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## RAILWAY ENGINEERING SECTION MEETING.

27 January, 1942.

RAYMOND CARPMAEL, O.B.E., M. Inst. C.E.,

Chairman of the Section, in the Chair.

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the meeting were accorded to the Author.

**The Chairman** observed that Mr. Wallace's Paper was the first to be delivered before the Railway Engineering Section. He hoped that others would follow, and he understood that if Papers from other railways were forthcoming, the Author would be willing to supplement them by a further communication on behalf of the London, Midland and Scottish Railway.

It was very fitting that the Author should present the first Paper, and he was sure that all would agree that the Section had been given an excellent start.

Railway Paper No. 1.

## "Permanent Way Tests and Practice on the London, Midland and Scottish Railway."


By William Kelly Wallace, M. Inst. C.E.


### Introduction.

After the last war standardization of permanent way design was achieved in Great Britain to a great degree, owing principally to the work of a Committee of Chief Engineers. The grouping of the railways, which took place in 1923, helped materially to extend the use of standard track, and

the accumulation of deferred maintenance from the war years produced greater relaying programmes than normal for a number of years, so that a large milage of standard track was soon in traffic. For a number of years some of the principal railways had been using British Standard bull-head 95-lb. rails for their main lines, and some systems the 85-lb. British Standard bull-head rails in addition on secondary lines. But the work of the Committee went further than this ; it even designed a standard chair, hitherto the chief example of individuality, and this was widely adopted. The standards of the 1920's to a large extent remain in use to-day, but with a number of modifications, and the Author trusts that this Paper will dispel the opinion held by some that standardization is a more polite way of spelling stagnation. There have been constant efforts to improve the design, materials, and methods used in the track on all lines. On the London, Midland and Scottish railway approximately 7,900 miles of running line is laid with standard track, that is, 60 per cent. of the total running lines owned.

## User of Permanent Way.

During the industrial depression in the 1930's, the traffic wear on the permanent way decreased, but in the later years of the decade, with the industrial recovery, demands on the track became more onerous.

The following figures are intended to show this. With the exception of those in column 4, they are all ratios based on the year 1929, the last pre-depression year.

Comparative User of Permanent Way.

| Year. | Engine-miles per equivalent track-mile. | Engine ton-miles per equivalent track-mile. | Train-miles per day booked at speeds of 60 m.p.h. and over. |
|---|---|---|---|
| 1. | 2. | 3. | 4. |
| 1929 | 100 | 100 | — |
| 1930 | 97 | 97 | — |
| 1931 | 92 | 95 | — |
| 1932 | 90 | 93 | 100 |
| 1933 | 89 | 96 | 205 |
| 1934 | 94 | 103 | 235 |
| 1935 | 95 | 107 | 566 |
| 1936 | 99 | 114 | 630 |
| 1937 | 101 | 116 | 1,470 |
| 1938 | 98 | 113 | 1,540 |

Column 2 shows the engine-miles per equivalent track-mile, as the locomotive forms the most destructive part of the rolling stock from a permanent way point of view. The equivalent track-miles are the total

milage of running lines plus one-quarter of the milage of sidings. From this it would appear that the user of permanent way on the London, Midland and Scottish Railway in 1937 was only slightly more intense than the pre-depression total of 1929, but this ignores two very important items, namely, (*a*) the increase in the weight of locomotives; (*b*) the greatly increased milage of trains timed at 60 miles per hour and over, start to stop.

It is impossible to give accurate figures for the increased user due to increased weight of locomotives, but column 3 (engine-ton miles per equivalent track-mile) is undoubtedly an understatement. The equivalent track-miles are obtained as before; the engine ton-miles are obtained by multiplying the milages run by tender and tank engines by the average weight of each type respectively. The weight of tenders is excluded in the case of tender engines: this assumes equal unit milage for the different types of locomotive, and is a known understatement, as the new standard designs run more miles per day than the old, and surplus locomotives, pre-war, were in all cases old types of lighter weight.

It was not until 1932 that any trains on the London, Midland and Scottish Railway were timed regularly at 60 miles per hour, start to stop; therefore that year has perforce to be taken as the base, but it will be noted from column 4 that the subsequent increase was extremely rapid.

Generally the Table shows that the demands on the track were greater in and after 1934 than before the depression, and at the end of the period the increase was probably not less than 25–30 per cent. Owing to improved methods of maintenance, the increased user has not been accompanied by a corresponding increase in expenditure, an outstanding contributor to this being the use of measured shovel packing.

## Transition Curves and Alignment.

The main lines of the system were originally laid out with circular curves springing directly from the tangents, but as the speed increased the necessity for transition curves became apparent, and by 1930 all severe curves on the main lines had been re-aligned with transition curves, utilizing the Hallade instrument and methods.

The acceleration of passenger trains, and particularly the running of ultra-high-speed trains such as the "Coronation Scot", showed that transition curves and curve maintenance, which were perfectly satisfactory at speeds of 60 and 70 miles per hour, were uncomfortable at speeds of 90 miles per hour; and this applied also to transition from one radius to another within a compound curve.

Preparatory to putting the "Coronation Scot" into regular service, a test-run was made, from Euston to Glasgow and back, in November 1936, the journey in each direction being done in less than 6 hours; and as a

result of these runs, and of the Hallade records obtained thereon, it was decided to put in hand a programme of work, where necessary, either to improve the running or to ease a speed restriction. The test-run showed that in the main, a maximum speed of 90 miles per hour could be permitted throughout, except, of course, over curves and junctions where permanent speed restrictions existed. It was found necessary to instal new transition curves in a number of the easy curves which had not been transitioned before, and many of the existing curves had to have their transitions lengthened and eased. In dealing with transitions, a chord is used, the length of which, in feet, is 1·61 times the maximum anticipated speed in miles per hour, and it was necessary to make the length of the transitions a minimum of 5 half-chords.

The running of ultra-high-speed trains increased the range of speed run on the line, and raised the question of cant deficiency. It was found that on a well-aligned curve a 3-inch deficiency was neither uncomfortable to passengers nor unduly noticeable, but that very small faults in alignment with this cant deficiency were both uncomfortable and noticeable. Hence in certain instances up to 3 inches deficiency was permitted, but such cases were few in number, and occurred only in places where the "Coronation Scot" would be the only train attaining such deficiency.

Preparatory to the regular running of this train, 269 curves were re-aligned, constituting a total single-track milage of 244 miles. The permanent alignment of these curves was marked by concrete monuments sunk in the 6-foot way in the usual manner; 17,432 pegs were used for this purpose.

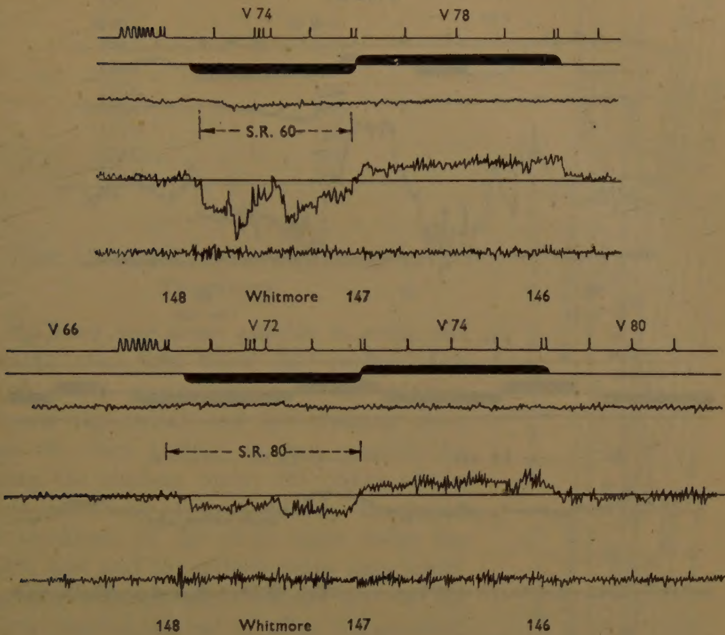
In addition to re-alignment of the curves, nineteen junctions were improved and 14 miles of tangent was re-aligned and pegged to "dead straight."

Much of the work in connexion with the improvement of junctions was due to altering them to the two-level design, which will be referred to later. Apart from this major two-level work, numerous simple connexions to and from the main lines were two-levelled in order that the main line cant might be maintained at the correct amount. As the result of this work, twenty existing speed restrictions have been relieved or abolished, and in twelve cases where speed restrictions would have had to be imposed, the improvement carried out rendered this unnecessary. The results of a few of the improvements made after the running of the trial train are shown in *Figs. 1, 2, 3,* and *4*. In each case the upper record was obtained on the test-run, and the lower in regular service after alterations had been carried out.

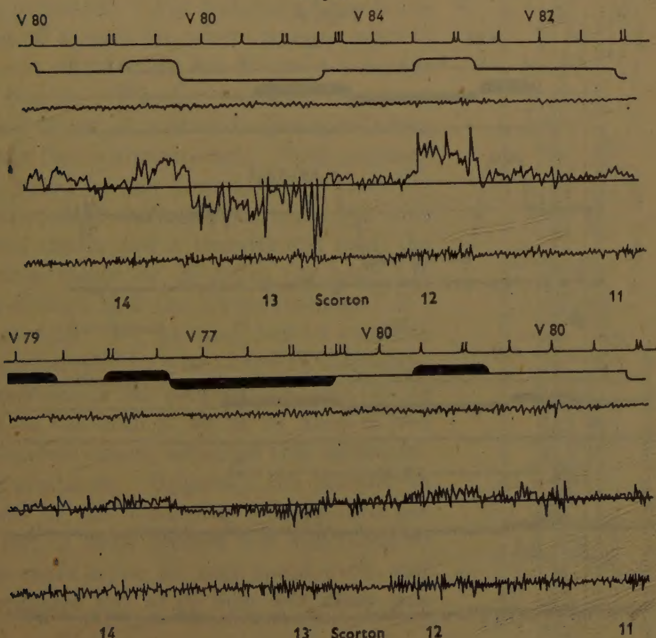
A general re-timing and acceleration of trains on the Midland Operating Division followed, and entailed similar work on curves.

To give an idea of the magnitude of the work done by the Engineer's Department, it may be stated that the milage of single-track curve re-alignment annually was as follows :—

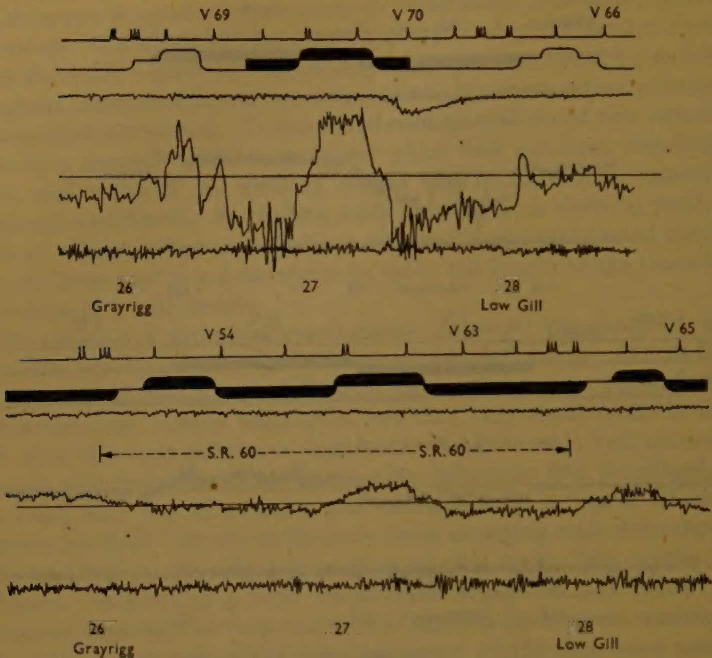
*Figs. 1.*


V 74
V 78
S.R. 60
148
Whitmore
147
146
V 66
V 72
V 74
V 80
S.R. 80
148
Whitmore
147
146

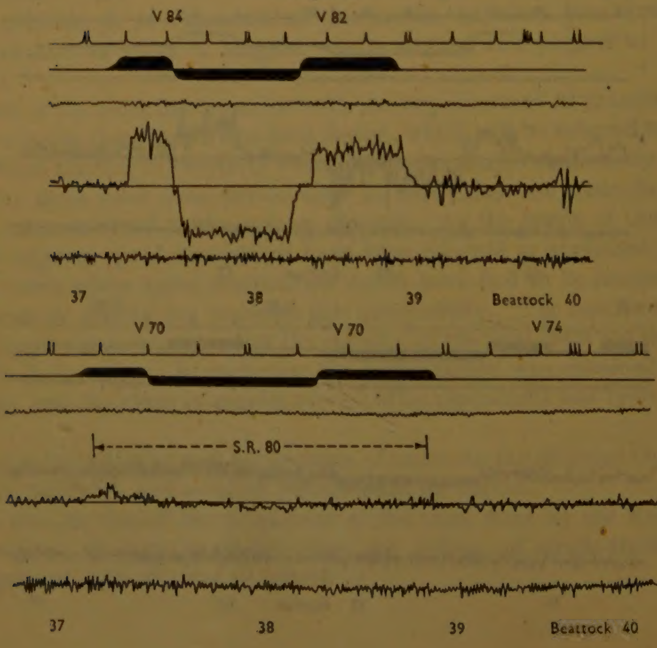
*Figs. 2.*


V 80
V 80
V 84
V 82
14
13
Scorton
12
11
V 79
V 77
V 80
V 80
14
13
Scorton
12
11

*Figs. 3.*


V 69
V 70
V 66
26
Grayrigg
27
28
Low Gill
V 54
V 63
V 65
S.R. 60
S.R. 60
26
Grayrigg
27
28
Low Gill

*Figs. 4.*

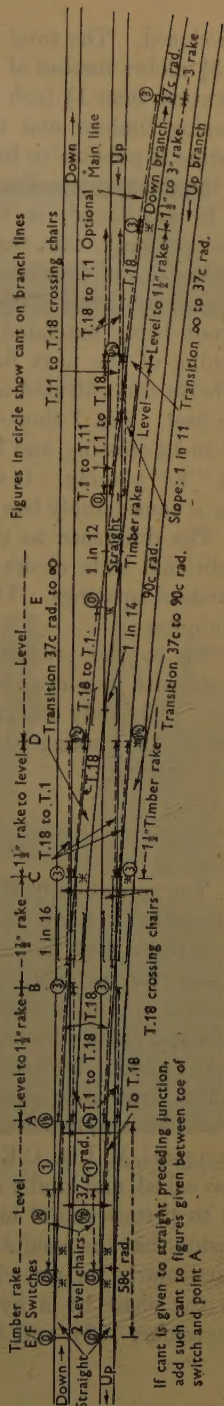

V 84
V 82
37
38
39
Beattock 40
V 70
V 70
V 74
S.R. 80
37
38
39
Beattock 40

| | |
|---|---|
| 1929 . . . . . . | 50 |
| 1930 . . . . . . | 75 |
| 1931 . . . . . . | 120 |
| 1932 . . . . . . | 129 |
| 1933 . . . . . . | 150 |
| 1934 . . . . . . | 153 |
| 1935 . . . . . . | 163 |
| 1936 . . . . . . | 165 |
| 1937 . . . . . . | 297 |
| 1938 . . . . . . | 205 |

## The Use of Two-Level Chairs in Junctions.

Hitherto one great trouble in point and crossing work has been the impossibility of obtaining superelevation in the turnout between the switch and the crossing, other than the very trifling amount possible by adzing the timbers under the chairs of the inside rail; but by progressively increasing the thickness of the chair seats under the switch heel and the outside rails, thus beginning the superelevation at the heel of the switch planing instead of after the crossing, an increase in the speed through turnouts can be permitted. *Fig. 5* shows a branch line turning off a main line where no concession in alignment of the main line is made in favour of the branch. Whether two-level chairs are provided or not, it is obvious that speed along the main line is unrestricted. With ordinary chairs, speed on the branch would probably be restricted to 30 miles per hour, but with two-level chairs and a transitioned lead, the restriction would be 50 miles per hour. It will be noticed that the layout includes " E " switches with " F " planing, 1-in-16 common crossings followed by 1-in-12 switch diamonds. Two-level chairs are used on the main line as well as on the branch, so as to keep it free from superelevation, although this entails inserting gradients. Originally the increase in thickness of the chair-seat was $\frac{1}{12}$ inch per chair, but in some layouts this was found to give too rapid a rise for high-speed work, and an alternative rise of $\frac{1}{16}$ inch per chair was

*Fig. 5.*




Sketch Plan showing Method of "Two Levelling" Junction off Straight.

introduced. The total increment in chair-seat thickness is $1\frac{1}{2}$ inch, that is, $3\frac{1}{4}$ inches instead of the standard depth of $1\frac{3}{4}$ inch. If greater super-elevation than $1\frac{1}{2}$ inch is necessary, this can be attained by canting the crossing timbers and using two-level chairs in both switch rails, thus making it possible to have 3 inches cant on a diverging road and no cant on the straight (see *Fig. 6*).

It was found, in applying standard permanent way in high-speed junction work, that the usual switch shown for a given angle of crossing resulted in an excessive lateral thrust at the switch-point. This can be reduced by fitting a longer switch, but frequently conditions prohibit the layout being extended in length. It was found, however, that if the planing of the next flatter switch were given to the blade, the thrust hitherto concentrated at the switch-point was divided over the point and the heel. *Fig. 7* shows the effect of a normal "D" switch in advance of a 1-in-12 crossing, and in dotted lines the effect of giving the "D" switch the "E" planing. It will be seen that the maximum thrust on the dotted line is considerably less than that on the solid.

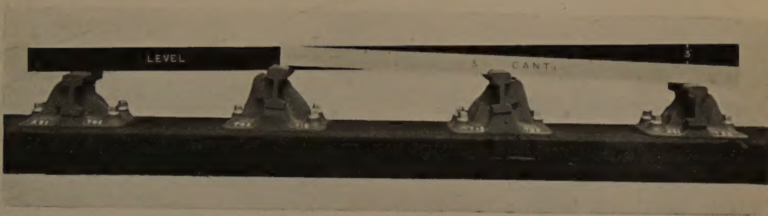
The difference to the platelayer lies in the fact that there are two additional slide chairs and then the ordinary heel chairs follow on at standard spacings. This reduces the number of special chairs to the minimum.

Up to the present, approximately fifty-three junctions have been relaid with two-level chairs, with notable relaxations in the speed restrictions. The only objection is that more patterns have to be kept in stock, but as the running has been improved, the day-to-day maintenance has been reduced.

## Spreading of Gauge on Curves.

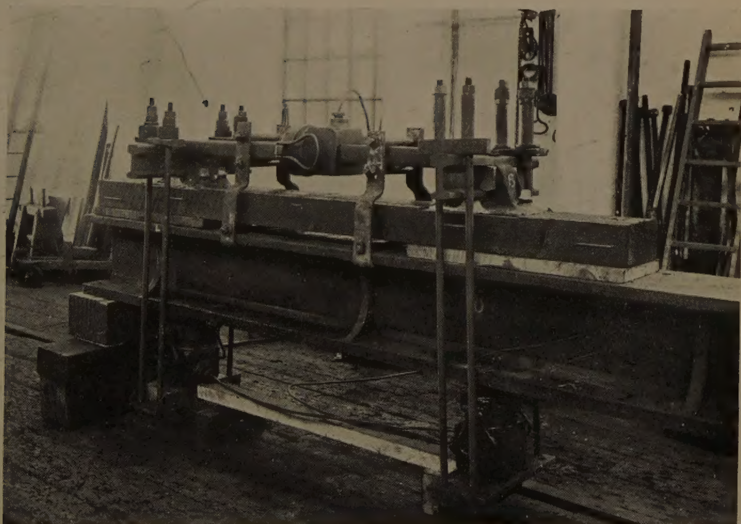
The spreading of the gauge on curves, which used to cause a considerable amount of trouble, has ceased to be a serious defect with the standard permanent way, but it was thought that trouble might arise when the milage run at high speed was increased materially. It was therefore decided to run a series of tests between London, Midland and Scottish standard track with screw fastenings, Great Western through-bolted track, and London, Midland and Scottish through-bolted track, chaired at L.M.S. creosoting depots. The standard permanent way of both lines is well known, but in order that no mistake might be made, Mr. Raymond Carpmael, M. Inst. C.E., then Chief Engineer of the Great Western Railway, was asked, and kindly agreed, to chair the test-sleepers in one of his depots, or to permit one of his regular contractors to do so. The object was to ensure that the results were fully representative of Great Western practice, particularly the screwing up of the bolts while a 10-ton load was applied to the chair by a hydraulic ram. The test-lengths were laid between September 1934, and April 1935.

*Fig. 6.*



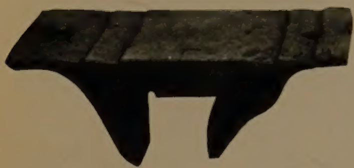

METHOD OF OBTAINING 3 INCHES OF CANT BY USING TWO-LEVEL CHAIRS AND CANTING OF TIMBERS

*Fig. 8.*



TRACK RESISTANCE TO LATERAL LOADING APPARATUS AND SPECIMEN UNDER TEST.

*Figs. 9.*



STANDARD CHAIR (G.W.R.) WITH SERRATED BASE, 2 HOLE FASTENING FOR THROUGH BOLTS.

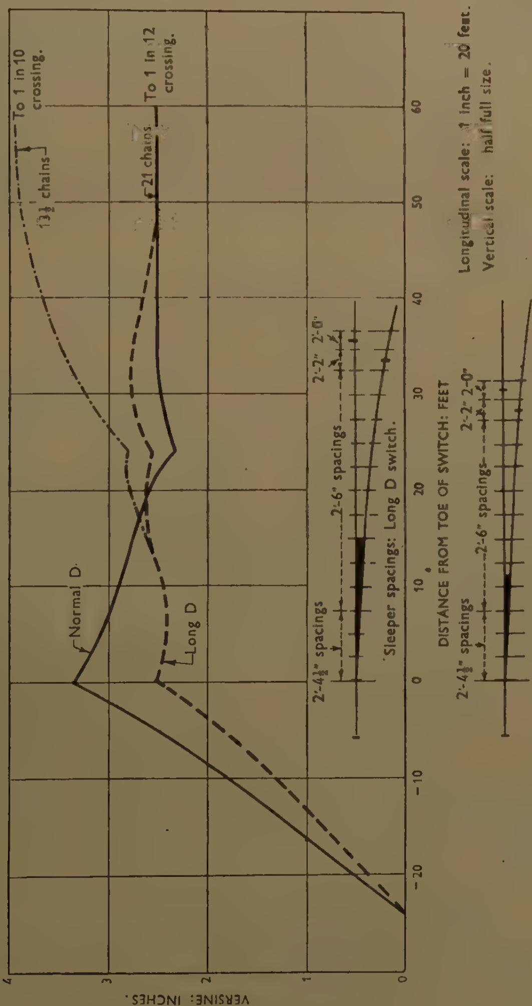
STANDARD A.S.I. CHAIR, 3 HOLE FASTENING (FOR SCREWS) WITH PROJECTING NIBS.

STANDARD A.S.I.A. CHAIR, 2 HOLE FASTENING (FOR THROUGH BOLTS) WITH FLAT BASE.

STANDARD CHAIR (L.N.E.R) WITH RIBS ON BASE, 3 HOLE FASTENING FOR THROUGH BOLTS.

Should the results show that through-bolted road is much superior, it would be impossible to adopt the full Great Western design in existing L.M.S. creosoting depots, as the screwing-machines are not fitted with

*Fig. 7.*




Thrust on "D" Switches 48-Foot 4-Inch Chord.

hydraulic rams to supply the vertical load on the chair while screwing up the through-bolts.

The London, Midland and Scottish design of through-bolted track utilizes a chair with a plain base. In the Great Western type the chair base has lateral serrations and the sleeper is adzed to fit these before

creosoting. In the L.M.S. type the sleeper was adzed flat as for the standard track. The sleepers throughout were supplied by the London, Midland and Scottish Company and were carefully selected so as to be comparable one with another. Ten places were selected where lateral stresses were high. In each location a length of standard road, one of Great Western type, and one of London, Midland and Scottish through-bolted type, was laid. Centre-punch marks on each chair located a gauge-distance between the chairs on each sleeper, so that any spreading of road could be measured on subsequent inspections.

It will be seen by reference to Table I, which shows the results of lateral measurements, that traffic conditions varied considerably, and it is thought that the test is a representative one. At one site the test was terminated owing to a derailment.

## Resistance to Lateral Loading.

In addition to the running tests mentioned above, tests were carried out at Crewe in conjunction with staff of the Research Department, in which horizontally-applied loads were imposed on chair-sleeper assemblies carrying a constant 10-ton vertical load on each chair.

*Fig. 8* shows a sleeper under test, and the general arrangement can be easily seen. An old cast-iron girder supports the sleeper on timber packings representing the ballast. Short lengths of rail are secured in the chairs by solid steel wedges instead of keys, and by means of the vertical tie-rods a load of 10 tons is applied to each chair by jacks thrusting against the underside of the cast-iron girder. The object of using solid steel wedges in place of keys was to eliminate the widening of gauge due to compression of the key, as preliminary tests had shown that a considerable part of the spread of gauge was due to this cause. An increasing horizontal load was applied to the rail-heads by a horizontal jack in the centre.

Measurements were made at regular increments of horizontal load throughout, for

(1) arching of sleepers over central length of 4 feet 11 inches between chairs ;
(2) extension of sleeper between chairs or baseplates ;
(3) lift of the inner end, depression of the outer end, and lateral movement of each chair or baseplate, relative to the sleepers ;
(4) overall spread of gauge between centres of rail-heads.

In addition, in the case of the flat-bottom rails with baseplates, the following additional measurements were made :—

(5) horizontal movement of rail relative to baseplates ;
(6) lift and depression of rails relative to sleeper ;
(7) flexing of the web and foot of rail.

All sleepers were of Baltic redwood of good quality and were selected by one inspector.

In the case of the bull-head rail, six specimens of each type were tested, and for the flat-bottom rails, four of each type.

The assemblies supplied by the Great Western Railway and the London and North Eastern Railway were complete and ready for testing. The North Eastern sleepers were heart side up, in accordance with their practice. All Great Western and Midland sleepers were sap side up.

The bolted chairs were of the following types :—

Great Western : standard pattern with serrated base fitting into grooves pre-adzed in the sleepers.

London and North Eastern : with triangular-section ribs on base parallel to the rail, engaging saw-cuts in sleeper.

London, Midland and Scottish : B.S.I., with short, triangular section projections in base intended to be rolled into sleeper by traffic and followed up by tightening fastenings after the first few days in the road. For the test the bolts were tightened by spanner.

A.S.I.A., plain base.

Table II gives details of the more important assemblies tested. In addition, the spreading of gauge at 10-tons horizontal load is shown in the last column. Generally, the through-bolted designs show great stiffness, and there was not much to choose between the various designs.

A feature of the results is the large resistance offered by chairs having underside projections, but otherwise London, Midland and Scottish standard, secured by three screws, in both cases with omission of the felt pad. These give results comparable with those obtained from through-bolted assemblies, and failure was caused by breaking of the chair jaws. Further, the resistance of the chairs with two fastenings outside and one inside should be noted.

During each test the readings taken enabled the average contributions of each feature mentioned above to the overall spread of gauge to be computed from the geometry of the assembly. The agreement between the sum of the separate contributions and the directly measured spread of gauge at the rail heads was satisfactory.

In the case of the L.M.S. and the L.N.E. through-bolted chairs, failure in every instance was by breaking the outside jaw.

With the Great Western chairs, in two cases the breakage occurred in the seat of the chair, whilst in the others the jaw failed.

In the L.M.S. standard assembly, but without the felt pad, failure was by breaking the chair jaw, but with a felt pad failure had not occurred at 1 inch spread. In L.M.S. chairs with underside projections with screws and without a felt pad, failure was by breakage of the chair jaws. Chairs with three screws, two outside and one inside, gave a 1-inch spread of gauge without breaking the chair.

Tests with flat bottom rails terminated with gauge spread exceeding

1 inch, the single spike on the inside of the rail being insufficient to resist the overturning tendency.

*Figs. 9* show the bases of the Great Western, the L.M.S. bolted A.S.I.A., the L.M.S. screwed with underside projections A.S.I., and the L.N.E. bolted with underside ribs.

## Long Rails and Rail Expansion.

In June 1937, a mile of standard 95-lb. rail, but in 120-foot lengths instead of 60-foot, was laid in the down fast line near Boxmoor station, on a curve of 140 chains radius. The rails were rolled on the North-East coast and a small amount of kinking took place before they were laid in the road, so that some additional time had to be spent in adjusting them to satisfactory line and top after laying. The expansion spaces were standard plus $\frac{1}{16}$ inch, that is, $\frac{3}{8}$ inch instead of $\frac{5}{16}$ inch at the temperature of laying. Since they were got into satisfactory alignment they have given no trouble and run quite satisfactorily, but there has not been a sufficient decrease in maintenance to offset the extra cost of the rails.

In 1937, about 1 mile of track in the down fast line between Ampthill tunnel and Bedford was laid with 60-foot rails. Alternate joints were butted tight, the remainder having the normal expansion for a 60-foot rail.

Both fast lines through Watford tunnel, 1 mile 57 yards in length, were laid in 1937 with 60-foot rails butted together throughout, excepting for three lengths at each end, where the expansion increased to the normal allowance at the tunnel-mouth, and a gap of $\frac{1}{8}$ inch was provided every fourth joint to facilitate rail changing. At first the joints could not be detected when travelling in a train, but now they are audible—though to a much smaller degree than is usual in tunnels.

Sleepers at, or adjacent to, rail-joints usually require more maintenance and attention than those situated in the middle of the rails. In the United States of America it is generally held that 40 per cent. of the time spent in packing of sleepers is at or around rail-joints, and although the London, Midland and Scottish Railway's experience would not place this figure so high, it is a fact that joints require more attention than plain rail.

The experience in America of welding rails into long continuous stretches was studied, as well as the reports of the A.R.E.A. Committee on Stresses in Railroad Track. It was considered doubtful whether British Standard bull-head rails, with their much less lateral stiffness, as compared with flat-bottom sections, would carry the compressive stresses set up by summer temperatures without risk of the road buckling, and it was therefore decided to carry out some experiments in conjunction with the staff of the Research Department.

In September 1936 the joints were thermit-welded in two lengths of single track on a disused line lying in an almost North-South direction,

and situated on an embankment; each length was 507 feet long, and was free to expand at both ends; one length was on straight and the other on a curve of 63 chains radius. The rails were 30 feet long before welding and were of 84-lb. London and North Western section.

The rails were keyed up at a temperature of 20·3° C., and observed periodically until a day in the following March when the temperature was −1·0° C. The results of this preliminary experiment were :—

Variations of gauge were negligible, the maximum difference at any place being 0·08 inch.

Lateral displacements of the track were small, being within 0·02 inch over 75 per cent. of the length, and in no place exceeding 0·1 inch.

Longitudinal movements of the rails were considerable, owing to differences of temperature at various times, and the displacement of the rails in March from their original position in September with a temperature difference of 21·3° C. was as follows :—

| Rail. | Curved length. | | Straight length. | |
|---|---|---|---|---|
| | Displacement of ends : inch. | Total contraction : inch. | Displacement of ends : inch. | Total contraction : inch. |
| East | 0·53<br>0·54 | 1·07<br>(Steel keys) | 0·42<br>0·55 | 0·97<br>(Wooden keys) |
| West | 0·57<br>0·51 | 1·08<br>(Steel keys) | 0·41<br>0·46 | 0·87<br>(Steel keys) |

It will be noted that the contraction at each end of the rails was approximately equal, whilst the movement at the middle was negligible.

Vertical movements of the rails were small —0·1 inch on one occasion at one place; but at all other times the movements were of the order of 0·03 inch. It was deduced that the maximum stress in the rails occurred in the middle of each length, and was just over 2 tons per square inch for a temperature-difference of 21·3° C. There was no marked difference in the behaviour of the lengths held with steel keys from that held with wooden keys.

This experiment indicated that the welded lengths were too short to allow of the development of the maximum stress corresponding to the extreme temperature ranges likely to be encountered. It was, therefore, decided to extend the length of welded rails. Both lengths were welded together by inserting closure rails, and a further 1,172 feet of straight track was welded on at one end. By this means 2,213 feet in one welded length was obtained.

The road was keyed up on a warm day (3rd September 1937), steel keys being used throughout; they were driven towards the middle of the rails so that they would tighten their grip when the rails tended to contract. Observations were made periodically until the 9th April 1938. Then, the temperature being 30·9° C., lower than when the rails were keyed up, final measurements were made. The rails were then unkeyed and allowed to rest loosely in the chairs for a few days, and during this time the difference between maximum and minimum temperatures was considerable; this gave the rails a good chance of becoming free of stress.

On the 13th April 1938 the rails were re-keyed, the temperature being —5·5° C. The keys were driven towards the ends of the rails so that they should tighten as the rails tended to expand. During the same day, the temperature rose to 29·9° C., a rise of 35·4° C. in the day. No opportunity occurred for measurements to be made at a higher temperature, although observations were made periodically during the next five months.

Both trials proceeded satisfactorily, the rails withstanding the tensile stresses in the first instance and the compressive stresses in the second instance. The interest to the Permanent Way Engineer was in the resistance to compression, and the results of this trial only will be noted. No repairs were made throughout either trial, and it was not necessary to redrive any of the steel keys in either period. Variations of gauge were negligible; 0·06 inch was the maximum recorded.

On the day when the track was keyed up lateral movements were 0·06 inch at the ends only, and subsequently the ends moved farther sideways owing to the repeated pushing out and pulling in of the ends, sideways due to the repeated pushing out and pulling in of the ends, until eventually the displacements were 0·37 inch. In the central portion of the track, which had withstood the maximum stress changes, the rails have retained their correct gauge, and no lateral movement of consequence has been observed.

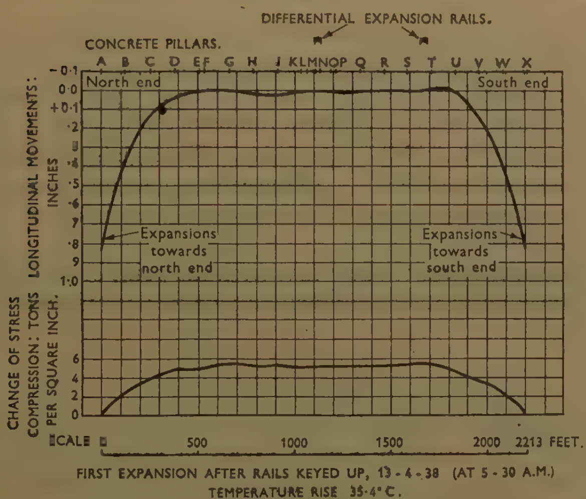
*Longitudinal movements.*—For the temperature-rise of 35·4° C., already mentioned, the sum of the two end movements was 1·68 inch and 1·69 inch for the east and west rails respectively. Five months later, the sums of the end movements were 2·34 inches and 2·25 inches for a temperature change of only 28·0° C.—greater movements despite a smaller rise of temperature. The explanation of this is that the ballast between the sleepers had become displaced near the ends of the length, owing to repeated movement in and out as contractions and expansions occurred during the five months, and the ballast in this condition offered considerably less resistance to the side face of the sleepers.

*Stresses in the central portion.*—*Fig. 10*, showing longitudinal movements, reveals that there has been no appreciable movement in the middle portion of the rail, and that at two points, 1,320 feet apart, there was no movement; small movements near the centre of the length were presumably due to the rails adjusting themselves to equalize stresses. It can

be accepted that the whole of the rail in the central portion was in complete restraint.

Simultaneously with the experiment on the long welded length, observations were made to determine the coefficient of expansion of the rail-steel; 300 feet of rail, similar to that in the welded length, was laid sideways on 2-inch diameter rollers supported on the flat tables of slide chairs. These rails were joined by fishplates, and a run of welding was added to ensure that no relative movement occurred between the adjoining rails; one end of the rail was anchored in a large concrete block built round it, and the

*Fig. 10.*




Longitudinal Movement and Stress Diagram of 2,213-Foot Free-Ended Rail (East) during Restrained Expansion-

other end was free to move because of expansion or contraction of the 300-foot length.

The value of the coefficient of expansion for the rails in question was found to be $11{\cdot}52 \times 10^{-6}$ per 1° C. Using this value, the average change of stress in the central completely restrained portion, 2,213 feet of welded length, was calculated to be 5·3 tons per square inch compression when the temperature had risen 35·4° C. on the 13th April 1938.

It was obvious from the stress curve on the graph, *Fig. 10*, that the stresses in the 507-foot lengths, originally tried, would have never increased materially. The corresponding curve for these shorter lengths would have had sloping ends meeting near the middle of the graph, and would not have had any horizontal centre portion if the temperature-change was more than 13·4° C. The corresponding stress of 2 tons per square inch would not increase in proportion to larger temperature-changes.

The result of the test showed that the rails each withstood 41·7 tons compressive load in the centre portion without tending to buckle. The track was laid on a formation once double line, so that there was 18 inches of ballast against the ends of the sleepers to resist any tendency to side movement.

It will be noted that both trials were made under the most severe conditions which could be imposed at the time, and although relaying of the track has to comply with a timetable, it should be possible to arrange that a long length is not keyed up under extreme conditions of temperature. By keying up at a moderate temperature, stresses may be tensile at times and compressive at others, and would be lower than those found in the experiment.

It was felt that the above results might not be representative of an open line, so it was decided to run a train several times over the length on a warm day when the rails would be under a fairly high compressive stress. A 2–6–0-engine and a short train were run over the length, at first slowly, and then up to a speed of 42 miles per hour. The highest average temperature during this trial was 38·5° C. In the central portion, the rails then had a calculated compressive stress of 6·6 tons per square inch, or a total load of 51·8 tons in each.

This experiment seems to show that from the point of view of stability, there is no objection to the welding of long lengths of bull-head track.

## Rail Joints.

One of the difficulties in bull-head track is in obtaining a satisfactorily designed joint. The ordinary British Standard design with 18-inch fishplates is distinctly unsatisfactory and becomes dipped long before the rails are worn out. The moment of inertia of the rail is 34·7 inches$^4$, whereas the inertia of the pair of fishplates is only 5·88 inches, that is, 17 per cent. of that of the rail.

A considerable improvement has been attained in the last few years by using short fishplates with only two bolts, enabling the joint sleepers to be brought closer together and giving more direct support to the assembly. Approximately 1,850 miles of track on the London, Midland and Scottish Railway are now fitted with short fishplates.

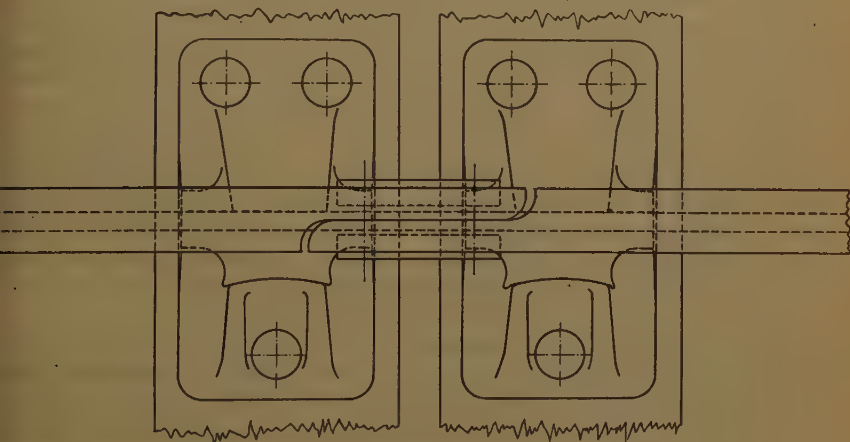
The L.M.S. short fishplate for 95-lb. bull-head rails is 9 inches long, and the standard arrangement gives a sleeper spacing of the 12-inch by 5-inch-joint sleepers of 1 foot $2\frac{5}{16}$ inches centre to centre. On secondary lines with 85-lb. bull-head rails, the arrangement is generally the same, except that the joint sleepers are 10 inches by 5 inches. Short fishplates are used in straight road and curves down to a minimum of 40 chains radius, but not in tunnels or on water-troughs.

Tests have also been made with a close-sleepered joint made of two 12-inch by 5-inch-joint sleepers bolted together with $1\frac{1}{8}$-inch crossing bolts.

The joint chairs are placed eccentrically on the sleepers to provide 1 foot $1\frac{9}{16}$ inch between centres of chairs when using the 9-inch fishplate; these joints are slightly more difficult to pack than the standard arrangement, but they appear to stand up better under traffic in wet situations, such as near water troughs, and it is proposed to make them standard for wet formations.

In addition to the above types for standard rails, an extensive trial has been made of the Brogden joint, which is of the vertical scarved type, the rail ends being reduced to half thickness and lapping against each other (*Fig. 11*). On the London, Midland and Scottish Railway the length of scarf was 9 inches and the joint was fitted with short fishplates

*Fig. 11.*



Arrangement of the Brogden Rail Joint.

and two types of washer-plate. Subsequently the joints have been fitted with four-hole fishplates of standard length. Two tests have been made, one on an electrified line and one on a steam line. The first was near Bushey station on the up line on a 98-chain curve with $\frac{3}{4}$-inch cant; traffic is 210 trains per day, averaging 220 tons in weight, with an average speed of 30 miles per hour. The joints were laid on the 24th November 1935, with plain washer-plates. Owing to difficulty in keeping the fish-bolts tight, special 6-inch fishplates were fitted in June 1936. The joints gave little or no trouble until 1942, when fatigue cracks were found in some of the fishbolts which had been in use for about 3 years. This type of failure was suspected from the experience of the test on the steam lines mentioned below, so that a special look-out was kept for it; the joints are also showing signs of batter, so that the object of the design—noiseless running—is not being attained.

Tests on the steam lines began by laying rails sufficient to give twenty-

eight joints in Brent Bridge storage sidings in November 1935, and as they showed no signs of distress under heavy locomotives, they were lifted and relaid in Willesden low-level goods line in March 1936, where they performed satisfactorily until 1937, when they were lifted and transferred to the up fast line near Cheddington in October. This was a severe test, as speeds run up to 90 miles per hour; the track is straight. After a few years' service breakages of fishbolts became numerous, and the help of the Research Department was called in to find out what movements were taking place at the joint, and the stresses imposed by traffic on the fishbolts. Inspection showed that movement was taking place at the joint with excessive stress on the bolts, the latter showing galling by the fishplates and the webs of the halved rails. The faces of the fishplates were also indented by the heads and nuts of the bolts; in addition, the inside faces of the halved rails were becoming worn at the top and bottom for about 1 inch in depth from the upper and lower surfaces of the rail; this was found to be due to the tightening of the fishbolts bending the half rail in its depth. When the fishbolts were tightened, the half thickness rail-web cambered in its depth to a maximum separation of 0·0085 inch. To overcome this, washer-plates, that is, fishplates planed so that they bed in complete contact with the web, were tried (fourteen joints being fitted in November 1938), and although this prevented the flexing of the rail-webs, the excessive stress on the fishbolts remained, and failures continued. On the suggestion of the inventor, special plates and fishbolts were fitted, giving a cup-and-ball joint effect, but these did not reduce the stresses in the fishbolts sufficiently. A special inspection was made in April 1939, both of the sections fitted with fishplates and of those with washer-plates, and as a result 18-inch fishplates were fitted throughout. The ganger reported that while the 2-bolt joints give considerable trouble, when fitted with 4-bolt fishplates they are easier to maintain to level than ordinary joints. Trains passing now make a tapping noise indistinguishable from that at ordinary joints. During the course of the experiments a special instrument was developed for recording the relative movements between the rails at a joint, and this gave the following results:

| Standard bolts and nuts. | Relative movement between rails at a joint: inch. |
|---|---|
| With 2-bolt fishplate . . . . . . . . | 0·034 |
| ,, ,, washer-plate . . . . . . . . | 0·041 |
| ,, ,, ,, with nuts slack . . | 0·047 |
| ,, 4-bolt fishplate . . . . . . . . | 0·022 |
| Bolts and nuts having spherical seats. | |
| With 2-bolt 7-inch fishplate . . . . . . | 0·097 |
| ,, ,, 9-inch washer-plate . . . . . . | 0·062 |

## LIFE OF DOUGLAS FIR SLEEPERS.

For many years the railways of Great Britain had drawn their sleeper supplies from the Baltic ports, but in recent years this supply has tended to fall off, and in consequence prices have risen to such an extent that Douglas fir sleepers from British Columbia became competitive; Douglas fir is a more difficult timber to creosote than Baltic redwood, and its life in the track has in a number of instances been disappointing. In the middle 1930's, a special investigation was made of a large number of Douglas fir sleepers that had been in the road for some time. In 1920 the London and North Western Railway used a large number of Douglas fir sleepers in various parts of the system; 101,400 being issued from Ditton creosoting depot alone. In 1934, thirty-one lengths of this input were located and a careful inspection was made of the 38,642 sleepers therein. The results of the inspection are given in the following Table:

| Sleepers. | Number. | Per cent. |
|---|---|---|
| Sound | 24,360 | 63·1 |
| Slightly split | 11,576 | 30·0 |
| Badly split | 2,274 | 5·9 |
| Decayed | 331 | 0·8 |
| Replaced | 101 | 0·2 |
| | 38,642 | 100·0 |

In order to check whether ballast was covering up defects, the sleepers of one rail-length in each ¼ mile were removed from the road and examined; forty-two lengths (2,768 sleepers in all) were thus dealt with. The result of the detailed inspection is given below:

| Sleepers. | Number. | Per cent. |
|---|---|---|
| Sound | 1,478 | 53·0 |
| Slightly split | 1,038 | 37·7 |
| Badly split | 67 | 2·5 |
| Decayed and split | 66 | 2·4 |
| Decay slight | 80 | 2·8 |
| Decay serious | 22 | 0·8 |
| Replaced | 22 | 0·8 |
| | 2,768 | 100·0 |

These sleepers were 7 per cent. of the total number in the lengths examined; it will be noted that the percentage of sound or slightly defective sleepers was similar in both cases, showing that few defects were covered by the ballast.

Since this inspection seventeen lengths have been relaid, totalling 15,978 sleepers, with an average main-line life of 18 years. The actual condition when taken out of the road is as follows:

| Sleepers. | Number. | Per cent. |
|---|---|---|
| Sound | 10,471 | 66·0 |
| Slightly split | 2,676 | 17·0 |
| Badly split | 1,054 | 6·0 |
| Decayed | 1,637 | 10·0 |
| Replaced | 140 | 1·0 |
| | 15,978 | 100·0 |

It will be noted that the final classification does not differ widely from the previous inspections, which shows that there has not been a marked deterioration in quality since 1934.

In some cases the sleepers were renewed because the rails had reached the end of their life, so that more than 18 years' main-line life would have been obtained from the timber.

## Flat-Bottom Rails.

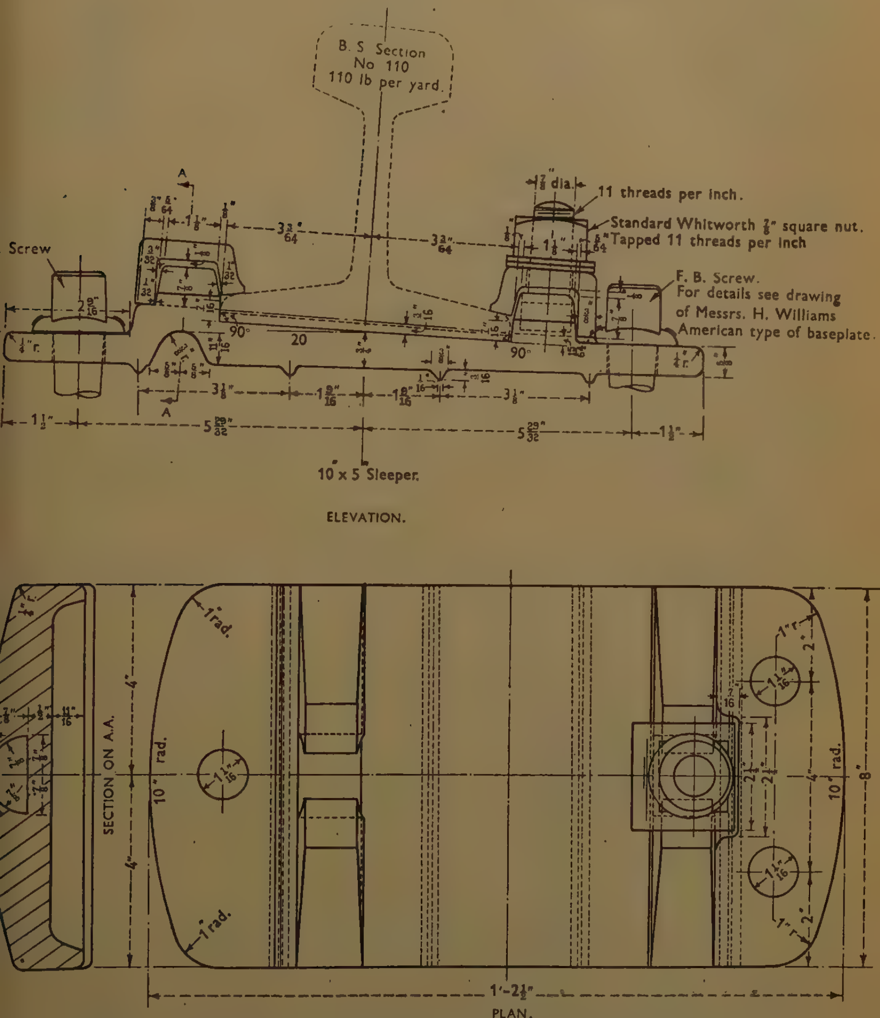
Discussions as to the relative advantage of bull-head and flat-bottom rails for use on British railways have continued for many years, and have been largely inconclusive, one reason being that there was no experience in Great Britain of the use of flat-bottom rails in main lines. It was obvious from inspection in other countries that flat-bottom rails could form a first-class road. Furthermore, American track was standing up well to traffic with a very small expenditure on maintenance during the depression years. It was accordingly decided to make an extensive trial of flat-bottom road, and in 1936 approximately $5\frac{1}{4}$ miles were laid in nine different places. They were grouped near London on the old Midland line, north of Leicester on the same line, and on the Caledonian main line north of Carlisle. In all cases British Standard 110-lb. flat-bottom rail was used, which has a head approximately equal in area to the 95-lb. R.B.S. The rails are of medium manganese steel and British Standard fishplates are used. The moment of inertia of the rail is 57·2 inches$^4$, and that of the pair of fishplates 12·35 inches$^4$, that is, 21·4 per cent. of that of the rail, which is more favourable than in the case of 95-lb. bull-head rail. For baseplates and fastenings of rail to baseplate and baseplate to sleeper, two main designs were got out, one based on German practice and one on American, both utilizing a double shoulder-plate (*Figs. 12* and *13*, and Figs. 14, Plate I).

German practice is represented by one type very similar to the *Reichsbahn* and another with a rolled-steel plate on similar lines. The American types comprise one with a steel baseplate and another with a cast-iron plate, the rail fastenings in both cases being a mushroom-headed screw. In addition, two short lengths of American type baseplate were used, each fastened by three elastic spikes. In each position a length of not less than 440 yards of British Standard track was laid at the same time as a control; the maintenance gangers make special returns weekly of

the amount of time spent on the flat-bottom and bull-head control lengths.

Table III gives the summation of these figures up to the 15th June, 1941,

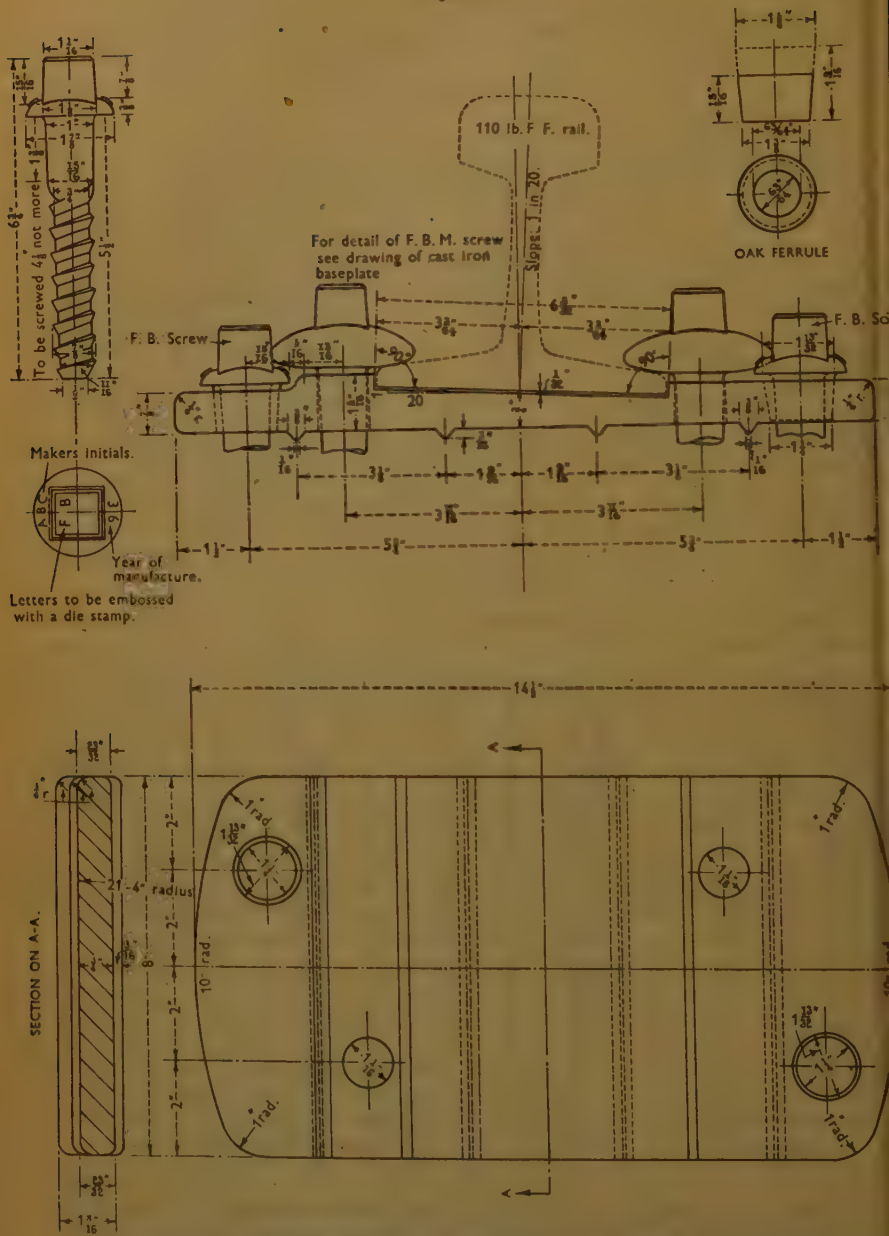
*Figs. 12.*




German Type Base Plate for use with 110-lb. Flat Bottom Rail.

expressing each length in the ratio it bears to the adjoining R.B.S. control-length, which is rated as 100, the actual man-hours having first of all been converted to equivalent man-hours per mile per annum. It will be noted

*Figs. 13.*




American Type Base Plate for use with 110-lb. Flat Bottom Rail.

that in addition to lengths with the standard twenty-four sleepers per rail, a number were laid with twenty-nine sleepers.

Some of the locations have proved to be somewhat unfortunate; for example, the "C" group are situated in a piece of line which is affected by movement of the formation, leading to excessive expenditure on lining, and also packing in the case of items C.1 and C.2.

The fastenings securing the baseplate to the sleeper in the type termed "Colville's German" use of necessity a very short ferrule, and this has proved to be easily crushed; hence the large amount of time spent on fastenings in the cases of B.4 and C.3. It is considered that the time spent on fastenings in jobs E and F is distinctly under-returned.

After this road had been under test for a little over 2 years, it was decided that further information was desirable, and another twelve lengths ($6\frac{3}{4}$ miles) of 110-lb., and eight lengths (5 miles) of 131-lb. flat-bottom rails were laid in 1939 at seventeen different localities widely distributed over the system. The 110-lb. rail was the same as before, but whereas the 1936 rails all had the standard B.S. four-hole fishplate 20 inches long, the 1939 rails had a modified section of plate utilizing a 1-inch diameter nibbed fishbolt with B.S. fine thread, and three of the lengths had short 10-inch two-hole plates of the same cross-section. With the 20-inch plate the joint sleepers are 2 feet $1\frac{3}{16}$ inch apart, centre to centre, and with the 10-inch plate 1 foot $3\frac{3}{16}$ inches apart. The 131-lb. rails are of American Railway Engineering Association standard section with corresponding fishplates which are either 24 inches long, with four bolts, 1 inch diameter or 36 inches long, with six bolts, 1 inch diameter. With the 24-inch fishplate the joint sleepers are 2 feet $5\frac{3}{16}$ inches, except for a few which are close-sleepered, and in the 36-inch plate the centres are 2 feet $0\frac{11}{16}$ inch. The 131-lb. rails are of medium manganese steel, B.S.S. No. 9 (1935). The fishplates are of Class B steel B.S.S. No. 47 (1928), but with the carbon-content raised to 0·36–0·44 per cent. The 10-inch fishplates for the 110-lb. rails and all those for the 131-lb. rails are oil-hardened. The steel baseplates are also of Class B steel B.S.S. No. 47 (1928). The moment of inertia of the 131-lb. rail is 88·5 inches$^4$, and of the pair of fishplates 32·2 inches$^4$, that is, 36·4 per cent. of that of the rail—the most favourable proportion yet used in the road.

In 1936 the rails were laid with normal expansion, but in 1939 the expansion was reduced practically 50 per cent. below standard. An R.B.S. 95-lb., standard control length (at least $\frac{1}{4}$ mile long) was laid at the end of the flat-bottom road and at the same time. In the latter test only two main types of baseplate were used, one of a modified German design, but using a cast-iron plate, permitting the use of standard chair screws and ferrules, and the other using three elastic spikes, two spikes on the inside and one on the outside of the rail. Half of these baseplates were of cast iron and half were of rolled steel (Figs. 15, 16, 17, 18, 19, and 20, Plate I). In the tests made in 1936 the elastic spikes were one inside and two outside the

rail; the alteration was made as a result of the resistance to lateral loading-tests referred to elsewhere. The sleepering was either twenty-four or twenty-six per rail length. In these cases also the gangers made a special return, and the results to 13th July 1941 are shown in Table IV. The elapsed period is considerably shorter than in the previous Table, which may account for some of the rather surprising numerical results.

Packing probably comprises the original time spent in getting the road to a bearing. As will be expected from the greater lateral stiffness, the flat-bottom rail generally requires less lining, but when it does require lining, the additional stiffness increases the cost; the fishplates and fish-bolts take more labour to oil and put on, but it is questionable whether it is necessary for this to be done to the same extent as in B.S. road.

There is no doubt that to get accurate comparative figures of maintenance, it would have been better to have had special technical staff detailed to check the charging of the time currently, but this was not feasible and the figures given are all that exist. It does seem that flat-bottom road requires less day-to-day maintenance than bull-head road, and had it not been for the intervention of the war, it was proposed to relay in their entirety some lengths with flat-bottomed road, and then definitely check up on the man-hours required for the various jobs.

The present arrangement with both types on lengths tends to give incorrect figures; for example, in summer time the extra walking of lengths to see that keys are tight is returned, whereas a flat-bottom road does not require this attention at all.

In 1939, the cheapest type of flat-bottom road was the 110-lb., with cast-iron baseplate and elastic spike fastenings. This cost approximately 6½ per cent. per mile more than the standard track, but if the flat-bottom had been the standard track some of the components would have been supplied at a lower price than for the small orders given and the price of the rolls would have been spread over a much larger tonnage of rails. Similarly, the cheapest design using 131-lb. rail also had cast-iron baseplates and elastic rail spikes and cost approximately 30 per cent. more than standard bull-head, and the same comment can be made in this case. The rolled-steel baseplates were a costly item, being approximately 115 per cent. more expensive than the cast-iron chair. Presumably this is the item for which bulk orders would procure the greatest reduction in price, but at any rate the cast-iron baseplate appears to be giving quite satisfactory service.

Some months after the 131-lb. rail was laid it was noticed that the running-on ends of the rails were battering about 1 inch from the joints; this did not occur in the sorbitic-treated rails. To prevent this the rail ends have been hardened in the track by means of an oxy-propogas flame and water quenching; the hardening extends 2 inches from the rail end at the running-on end only. The Brinell number of the rail-head originally was 220–240, and this has been increased to 300–350. A similar defect has not developed in the 110-lb. rails.

Many other points connected with tests and practice could be touched on if time permitted. Possibly some can be dealt with later.

ACKNOWLEDGEMENTS.

Thanks are given to Sir Harold Hartley, C.B.E., M.C., F.R.S., Vice-President and Director of Research, London, Midland and Scottish Railway, for permission to publish the information contained herein; to Mr. T. M. Herbert, M.A., M.I. Mech. E., Research Manager, London, Midland and Scottish Railway, for data from his Department; and to colleagues in the Engineer's Department—Mr. James Briggs, M. Inst. C.E., Permanent Way Assistant, Mr. W. M. Bond, Hallade Assistant, and Mr. N. W. Swinnerton, Assistant (Permanent Way Improvements), for preparation of drawings and data.

The Paper is accompanied by seventeen sheets of diagrams and three photographs, from which Plate I, the Figures in the text, and the half-tone page plates have been prepared.

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## Discussion.

**The Author,** in introducing his Paper, exhibited a film illustrating the process of measured shovel packing, and also showed a series of lantern slides.

**The Chairman** said that most of those present were railway engineers. He was sure that they would have learned a great deal from the Paper, and also that any members of the audience who were not railway engineers or conversant with railway practice would agree that there was assuredly no stagnation in the engineering departments of the railway companies.

He concurred with the Author that standardization did not result in stagnation, and from personal experience he knew that often the discussion of the possibilities of standardization resulted in the presentation of new ideas. He had had something to do recently with the standardization of concrete sleepers for use on railways, and he was sure that the Author, who was also a member of the Sub-Committee dealing with the matter, would agree that the discussions which had taken place had put some new ideas into their heads, with considerable advantage. The standardization of chairs had proved to be of great benefit. Their types used to be legion, and much trouble had been experienced on the Great Western Railway, whilst on the London, Midland and Scottish Railway, into which several important railway companies had been absorbed, the number of types of chairs must have been appalling. Another instance of standardization was that of steel sleepers; some consulting engineers thought that a radius of $\frac{3}{16}$ inch between the horizontal table and the return ends was ample, whilst others considered that it ought to be $\frac{7}{16}$ inch, and the number

of types of sleepers was legion, with no advantage whatever. He had been a member of the Committee which dealt with that subject and he considered that standardization had definitely produced good results.

An outstanding feature of the Paper was the Author's statement that, in spite of the very considerable increase in the use of the track, in the weight of locomotives, and in the number of train-miles at a booked speed of 60 miles per hour and more, no corresponding increase in track maintenance expenditure had occurred, owing to improved methods of maintenance. Such excellent results were very largely the consequence of research work and of the practical manner in which the engineers and the men working on the line had given effect to the lessons of that experimental work. The Author had furnished some very valuable details with regard to the improved methods of maintenance adopted.

In itself cant deficiency did not result in bad running if the curves were well aligned; but errors in alignment, with resultant errors in super elevation, might, and usually did, cause uncomfortable riding.

The maintenance of reasonably high speeds for long distances was of more importance than the attainment of very high speeds over comparatively short distances. Those very high speeds were very largely rendered necessary to offset slower running over sections subject to speed restrictions. The Author was thoroughly justified in emphasizing the importance of reducing such speed restrictions to the very lowest limit, and he had described some very practical ways in which that could be done.

The Chairman observed that, with regard to the spreading of gauge, the reduction effected in that trouble was due to improved methods of attachment of the chair to the sleeper. Naturally he was wedded to the Great Western through-bolt, which was introduced in about 1900. A few years ago the chief engineers of some of the other railways began to give serious consideration to the advantages of the through-bolt and had been testing it out on the track, with, he understood, satisfactory results.

He had noted the Author's remarks about the comparative tests showing the different lateral thrusts, with the chairs attached to the sleepers by the one method or the other; but it would be interesting to have a similar comparison on track that had been in the road for, say, 20 years. Did the screw spike hold as well when the sleeper was past its prime as it did when the sleeper was new?

With regard to long rails and rail expansion, the objects in view, in reducing the number of rail joints required, were quieter running and reduction in maintenance costs. The Author had asserted that the higher cost of the 120-foot rails was not offset by the reduction in maintenance costs, and it would be very interesting to learn whether in his experience the cost of welding rails into long lengths was, apart from any other consideration, justified by the saving in maintenance costs.

Like the Author, the Chairman had had an opportunity of inspecting

American track and had been considerably impressed by it. He thought that if railways could start *de novo* in Great Britain they would probably introduce the American type of track, possibly with some small modification, instead of the bull-head rail; but there was one possible objection upon which the Author had not touched, namely, that in America and other countries where the flat-bottom rail was used the sleepers were of hard woods, such as oak and beech, which were almost unobtainable in Great Britain. The use of soft woods would entail the use of base-plates larger than those required for hard woods. It would be interesting to have some information on that point from the Author.

He fully appreciated the Author's difficulty in obtaining correct cost comparisons, even from the extensive trials that he had undertaken. That arose, as the Author had pointed out, partly from inability to give bulk orders, which would reduce the cost of the rails and the other component parts to practical limits. If a change-over from bull-head to flat-bottom rails was made in Great Britain, a time would come when the cost of components in smaller quantities would increase to such an extent that not only would the change-over be a very lengthy process but also towards the latter end of the change-over the costs of keeping the gradually expiring lengths of bull-head rails in commission would mount up very considerably.

Experience could be gained only by such practical tests as those indicated in the Paper. An American engineer had once told him that railway engineers were the most conservative body of men in the world, and he thought that was said from a knowledge of the responsibilities of the railway engineer. Trials and tests had to be undertaken with due regard to speed, and must inevitably take time. Some years ago a man who wanted to sell him some hardwood sleepers had assured him that they would last for 30 years and that their higher cost was justifiable. His reply had been: "Very well, I will give you an order on one condition, namely, that you will come back in 30 years' time and see whether what you have said has proved to be true. If it has, I will give you another order."

**Mr. V. A. M. Robertson** observed that he would confine his remarks to the subject of rail welding, which was a problem in which the engineers of the London Passenger Transport Board had been particularly interested; in fact, he thought that they had been pioneers in the matter, for it was in 1933 that they had welded rails in lengths up to 90 feet.

In 1934, while in Berlin, he had visited the welding installations of the German State railways and various welding works, and had been very impressed by what was being done. In 1937 he had visited America, and during his tour of investigation had spent considerable time in studying the question of welding rails. He had spent four days with the late Mr. H. S. Clarke, of the Delaware and Hudson Railway, who was, he thought, the leading expert in America on the welding of rails into long lengths. Up to

that time the experience of the London Passenger Transport Board had resulted in his holding the opinion, confirmed by others, that welded joints of the type used hitherto did not offer a solution of the Board's problems. They were thermit-welded, and he would go so far as to say now that he would not put a thermit-welded joint into the track. One reason why he had been sent to Berlin and to America was that he might obtain information on flash-butt welding.

In discussing the question of welding with engineers and others, both in Great Britain and abroad, he had always insisted that, although the axle loads of the trains of the London Passenger Transport Board were very light in comparison with those on main-line railways, the Board should expect to obtain some satisfactory results from a tup test on a welded joint. He remembered talking to a Hungarian engineer who thought that that was nonsense, because a fishplated joint was not nearly so strong as the rail itself, and as one did not tup-test a fishplated joint, why should one tup-test a welded joint ? However, he had been insistent on the point. He had found that the late Mr. Clarke, to whom he had already referred, had put welded joints in the 131-lb. section rail without any tup tests at all, and although he had thought that trouble would be experienced on that account, that had not been the case, although a few joints had failed under load. He had seen some very long lengths of welded rails in the United States, and he thought that with the heavy axle loads in that country the railways were running a little risk. After some tentative experiments in 1935, a few miles of thermit-welded rails were laid in the tube railways in London, and no serious trouble had been experienced with them. It would seem essential, however, to have a rail of the normal hardness throughout if welding were to be justified ; and in order to determine the success or otherwise of flash welding rails of its standard composition the Board had sent rails of its own to Germany to be welded, with quite satisfactory results. As a result of that experience and because the Board was anxious to eliminate the " knock " of joints in the tube railways, he had obtained authority to purchase two flash-butt welding-machines, one of which was portable and mounted on a car, whilst the other was of the non-portable type and was used at the Board's works. Both machines had been very extensively used, for maintenance purposes and also for a large new works programme which the Board had undertaken from 1935 to 1940, and he had been told that up to the outbreak of war 10,000 joints on running and conductor rails had been welded. It would be realized that the standard for welded joints might well be considered to be an exacting one, and a continuous check of the results was obtained by making a careful record of all tests to complete destruction. The Board had done considerable pioneer work in connexion with the matter and had accumulated a great deal of valuable information, which he and his colleagues would be very glad to supply to any railway engineer who would like to have it.

In any consideration of rail welding the additional cost should naturally be set against the advantages to be gained, and perhaps those advantages were mainly comprised under the following headings: practical elimination of joint maintenance; reduction in track maintenance; increase in life of rails; smoother riding on account of reduction in rolling-stock maintenance; practical elimination of rail creep; considerable reduction in sleeper deterioration; reduction in signal bonding; and a very much quieter track.

The Author had brought out many interesting facts in his Paper, and not the least interesting feature was the way in which he had made available the benefit of the experimental work which his Company was constantly carrying out. The Author was always ready to pass on any information which might be useful to other railway engineers and for that they were all very grateful.

**Mr. A. S. Quartermaine** observed that the tests that the Author had made were not of the kind that many railway engineers were inclined to indulge in, namely, casual experiments. They were tests which, whether or not they gave results of a useful nature from the point of view of adoption, at least yielded information in which railway engineers could have confidence, and it was that kind of test that it was so desirable to have on record.

The feature which appealed most to him was the boldness of the Author's tests with the flat-bottom track. The controversy of flat-bottom versus bull-head track had existed since the first days of railways. He believed it was in 1835 that the first bull-head rail had been introduced, and the introduction of the flat-bottom rail had occurred at the same time. After the last war, in 1920, the Permanent Way Standardization Committee had had the question of flat-bottom versus bull-head track as the first item on its agenda; and, with the best will in the world it had arrived at the conclusion, which might or might not have been correct, that the chaired track should be perpetuated in Great Britain. The members of the Committee had formed their opinion very largely on their own experience of bull-head track and on other people's experience of flat-bottom track. As the Author had said, it was not until 1936 that a modern test had been made of flat-bottom track in fast-running line—and not only of flat-bottom track, but also of flat-bottom track with various types of fastenings, including the elastic spike, which was the very latest type. That test had been needed for years, and its value from the present time onwards would be considerable.

He supposed that the Author was as conversant as anyone with the pitfalls and difficulties of arriving at conclusions, but there was one comment which he would like to make in regard to the Author's test, which appealed to him because he himself had found it desirable to make a test with a different type of bull-head track on the Great Western Railway. The Author had compared the 110-lb. flat-bottom track with the 95-lb.

R.B.S. Mr. Quartermaine had worked out the weight of all the metal components in the 110-lb. flat-bottom track and the 95-lb. British Standard track, including the rails, chairs, chair-bolts, fishplates, and so forth. In the case of the 110-lb. flat-bottom track, with the cast-iron base-plate, the total weight per mile of the metal work was 271 tons, whilst the total weight per mile of the 95-lb. British Standard track was 251 tons. Even under mass-production conditions, he thought it was unlikely that the 271 tons of flat-bottom metal work would be bought more cheaply than the 251 tons of 95-lb. British Standard, and, to make a fairer comparison between the two, he would prefer the 110-lb. flat-bottom track to be compared with the 100-lb. British Standard or a 100-lb. bull-head rail. He mentioned that because the tests which were carried out in 1938 on the Great Western Railway with 100-lb. track were not tests with 100-lb. British Standard, but with the 95-lb. with an addition of $\frac{3}{16}$ inch on the top table of the rail, so that it was in all respects like the 95-lb. British Standard except that it was $\frac{3}{16}$ inch deeper on the top, making it a 100-lb. rail. That added 9 tons per mile to the weight of the rail, but the total weight was still less than that of the 110-lb. flat-bottom rail. He thought that if those two were compared, one would be more likely to obtain a proper comparison between the bull-head rail and the flat-bottom rail in regard to their lasting qualities and the value of their secondary life. The reason why the 100-lb. rail was tried on the Great Western Railway was that in 1920 that railway had reduced the weight of its rail from 97½ lb. per yard to 95 lb. per yard, in order to fall into line with the British Standard rail. As a result, the complaint was made that the rail was not so good, which was a natural complaint from any person who had been used to one type of rail and was then given a lighter one. It was described by gangers as being "whippy," which was an exaggeration, but nevertheless it was in fact not so stiff as the old 97½-lb. Great Western rail and was still less stiff than the 100-lb. rail. In 1938 and 1939 the Great Western Railway laid about 48 miles of the 100-lb. track and, generally speaking, it met with everybody's approval. He mentioned that, not as a criticism of the Author's tests, but as an indication that he felt that, with the increasing weight of locomotives and the higher speeds which were gradually being introduced, attention should be given to the question whether the continued use of the 95-lb. British Standard rail was keeping pace with the times and whether the slight extra cost in tonnage of rail per mile of the 100-lb. rail (there was no other cost) was not worth while on the most important routes with the highest speeds and the heaviest engines, bearing in mind that when that rail was worn it was of much greater service for secondary life in less important lines.

He would like to mention another point which was of interest with regard to the rail itself. The Great Western Railway had suffered during recent years from hunting on newly-laid 95-lb. track, and it was very unfortunate that newly-laid track, instead of producing perfect running,

lid not produce such good running as it did later on. That had been considered to be due to the radius of the top table, which was 12 inches n the 95-lb. rail, and an effort was made to overcome the difficulty. Tests were made by taking templets of the radius on the top of a large number of worn rails, and it was found that the radius was 12 inches; and after still further investigation, it was found that the centre of that radius was not on the centre-line of the rail, but was just off the centre-line, indicating possibly that the 1-in-20 cant was not really correct. In deciding upon a radius which would be on the centre-line of the rail and still pass through most of the worn rail, making a symmetrical rail, it was found that 7 inches was probably the best; but that was considered undesirably sharp, because it would tend to aggravate the hollowing of tires, and a 9-inch radius was adopted. About 60 miles of the 9-inch radius was put in, but no conclusive results had been obtained. Hunting had not been found on straight new track where the 9-inch radius existed, but that was negative proof, and when the war started the work was stopped. He did not know whether the Author could express any views on that subject, but he felt that it was very unfortunate that on new track the running was not so good as later on.

Short fishplates had, he believed, been more or less universally adopted n Great Britain. The Great Western Railway had used short fishplates n the Severn tunnel, and had found that they had caused fracture of the top of the rail in the corner of the fishing angle right underneath the fishplate. In consequence of that, the railway had discontinued the use of short fishplates under such conditions. It had been shown that in a situation where the life of the rail was from two to six years, as was the case in the Severn tunnel, broken rail-heads might be found under the fishplates in a short time, say a year or two, which was equivalent to 50 or 75 per cent. of the life of the rail. If that occurred in the Severn tunnel, was there a possibility that a similar thing might happen with short fishplates out in the open, after 50 per cent., 75 per cent., or more of the ordinary rail-life? He thought the answer was probably in the negative, because in the tunnel maintenance was not so high as it was outside and the battering of the rails was more severe. It was desirable, however, that consideration should be given to the question whether too much strain was being imposed on that short portion of the end of the rail.

He was glad that the Author was making such thorough tests of the through-bolt, because the Great Western Railway had advocated its use for a very long time.

He heartily endorsed the Author's statement that standardization did not cause stagnation, and he felt that the Paper formed another example of the manner in which one of four railway companies, working in friendly competition with the others, had shown that no possibility of stagnation would occur so long as there were such able people as the Author to give the railway companies the benefit of their views.

**Mr. W. A. Stanier** said that thousands of patents for rail joints had been taken out, but the locomotive still had to withstand eighty-eight blows per mile on a 60-foot rail, and he would suggest to his civil engineering colleagues that that was the important problem they had to face. Much had been done to provide means for making a good track, but bad battering still occurred and slack joints developed on the track, and that reacted on the whole of the rolling stock.

He had read the Paper with interest, and had seen the work which had been done, and he was sure that the technique which the Author had developed had given a better track on the London, Midland and Scottish Railway. He thought that the most promising thing was the butt-welding of rails in order to obtain longer sections.

**Mr. George Ellson** hoped that the information given by the Author with regard to the experimental lengths of track could be regarded as only an interim report, and that the Author would furnish further details from time to time, from both the economic and the track running points of view.

The Permanent Way Standardization Committee had sat for about seven years, and its first year was spent almost entirely in determining whether to recommend flat-bottom rails or bull-head rails as a standard. The Committee went to considerable trouble in order to obtain the fullest possible information. It had been stated that Great Britain was the only country to use bull-head rails, whilst the rest of the world used flat-bottom rails. What was the reason for that? The Author was making an excellent attempt to obtain some further information on the subject, but Mr. Ellson felt that it was due to the Standardization Committee to say that its work covered the whole life of the track, that it had information about the flat-bottom rails from other countries whilst its own members had information about the bull-head rails, and that it took into account the scrap value of the various materials at the end of the life of the track. As a result of its investigations, the Committee had come to the unanimous conclusion that in Great Britain the bull-head rail was more economical, and no one could say that the running was not quite as good as, if not better than, in other countries. That was the reason why bull-head rails were standard after the last war. He had sat on the Committee from 1920 onwards, and was therefore able to give that information from first-hand knowledge of the subject.

With regard to the question of doing without joints and using long lengths of welded track, it was known that that had been done very largely in America, on the railways in Victoria, Australia, and on the tube railways in Great Britain, whilst other British railways had been experimenting in a tentative way. Mr. Robertson's remarks on welded track referred mainly to railways in the tubes, although Mr. Ellson thought the Transport Board had some short lengths of welded track in the open. In the tubes the temperature was almost constant, and therefore the con-

ditions on the tube railways were ideal for long stretches of track without joints, but that was not so elsewhere. In 1938 he had laid about 1,200 yards of track in the open at Hildenborough, in rail-lengths of 180 feet, formed of three 60-foot lengths of rail welded together by the thermit process. He had experienced no trouble with that process. Jarrah-wood sleepers were adopted, seventy-eight being used for the 180-foot length of track; that was rather more than the standard number. The track was well ballasted, with a heaped-up shoulder at the ends of the sleepers, 2 feet in length beyond the sleeper-end. The coefficient of expansion, which was determined by measurement of a 45-foot freely-supported rail, was 0·0000068 per 1° F., which practically coincided with the coefficient of expansion given by the Author. The length of line in question was in the open, in a cutting which was hot in summer and fairly cold in winter; in fact, he thought the temperature-variations there were probably 100° F. more than they were in the tube railways. It was on the main London-Dover route, with fast and heavy boat-train traffic running over it; the most careful supervision was therefore maintained during the ensuing six months, and temperatures were recorded constantly throughout the daytime during the whole of that period, as also were the movements of the rails under the varying temperatures. No speed restrictions were imposed, and it was necessary that there should be no doubt about what happened with regard to the rails taking up temperature-variations. As a result of the very careful observations which were made, it was found that when a track rail free of stress started to expand the end sleepers, that was, those nearest the gaps, moved after a slight increase in temperature, and as that increase developed more and more sleepers moved. With an increase in temperature of 10° F. the expansion was absolutely resisted, and a stress of 0·884 ton per square inch was developed in the rail; for a 95-lb. rail that represented a load of 8·21 tons, which was sufficient to cause sixteen of the sleepers at each end to move. In the 180-foot length, between the seventeenth sleeper from one end and the seventeenth sleeper from the other end, a uniform load of 8·21 tons would have been induced, and after a total rise of approximately 23½° F. all the seventy-eight sleepers were found to move. The results showed that once the whole length of the rail was able to expand the free coefficient of expansion remained constant until the expansion-gap closed. The rail temperatures during the summer in question, which was not a very hot one, attained 120° F., and when there was an initial expansion-gap arranged at a temperature of 50° F. the maximum compressive load of the rail would be 34 tons, which would equal a stress of approximately 3·67 tons per square inch in the rail. If the rail was infinitely long, the stress would attain 57·5 tons per rail, or 6·9 tons per square inch. He wished to emphasize the fact that the rails were keyed up when the temperatnre was 50° F. If they were keyed up at a higher temperature, there would of course be correspondingly less

stress in the rails. Under those influences the track became a column subject to compressive load, and, especially when it was laid on a curve (unfortunately there were a good many curves in Great Britain), that load would have a tendency to distort it unless sufficiently strong restraining influences were brought into action. The track might be distorted laterally on either side, or vertically upwards. He thought that on a very hot summer day every railway engineer was very much relieved if, with the ordinary lengths of 60 feet, he had no distortion of track, and it was of the greatest importance that such distortion should be prevented with a substantial factor of safety. The lateral distortion was resisted by the frictional resistance between the undersides of the sleepers and the ballast, plus the resistance to movement offered by the shoulders of ballast at the ends of the sleepers. In addition, there was the strength of the track itself, the two rails tending to prevent lateral distortion. Possible upward movement was opposed by the dead weight of the track and the resistance of the rails to bending in the direction of their vertical axis. It would therefore be seen that the ballasting, both in quality and quantity, must be first-rate, and it was also important that the dead weight of the track should be as high as possible. For that reason, on the length of track in question Jarrah-wood sleepers were employed, the weight of which, taking into account the small increased number used, was 44 per cent. higher than the normal weight of sleepers in tracks. No difficulty had been experienced in maintaining the stretch of line in question true and level during the four or five years which had elapsed since the rails were laid.

**Mr. J. C. L. Train** wished to pay a tribute to the Author, as representing the London, Midland and Scottish Railway Company, for being so helpful in passing on his new ideas, many of which the London and North Eastern Railway Company had found very useful.

He would also like to suggest that, although the Author had not mentioned it, the Paper pointed a moral which younger men should note and which many older men had unfortunately ignored. The Chairman had mentioned, in his opening remarks, a view that railway engineers were essentially conservative. Mr. Train would go farther and say that they were too conservative. The Author, however, had shown that he was open-minded and was willing to try a new thing; and if only one out of ten new ideas was successful, that idea, if tried out, might repay a thousandfold the trouble that had been taken on the other nine ideas.

Mr. Train showed a series of lantern-slides, some of which illustrated practical propositions whilst others might be regarded as highly theoretical; but his object was to present ideas which members could ponder over and possibly develop later on. Those slides referred to continuous beam track, both of concrete and steel, and to special rail joints.

The engineers of the London and North Eastern Railway had a great admiration for the work done by the London, Midland and Scottish

Railway on curve re-alignment and transitioning, particularly in connexion with two-level chairs at junctions, in regard to which the London, Midland and Scottish Railway was a pioneer. The London and North Eastern Railway had adopted the two-level chairs at junctions, but before it ran its high-speed units, the "Silver Jubilee," the "Coronation," and so on, practically no re-alignment was done, as the re-alignment already carried out by the Hallade method was found to be good enough, largely owing to the length of the transition curve to which the Author had referred.

With regard to cant deficiency, after experiment he had adopted a value of 2½ inches as the allowable cant deficiency; that applied not only to high-speed trains, but to all trains. Headquarters, however, liked to control carefully the locations where it was to be applied and to be notified by district engineers when it was intended to adopt the 2½-inch deficiency. Actually it was based upon Hallade records in practice, which seemed to show that it was the maximum degree of cant deficiency which could be given with any comfort.

With regard to the merits of track with chair screws as opposed to through-bolted track, he understood that the Author did not at the moment see any reason to depart from the track with chair screws; and personally he thought that its advantages in the event of derailment should be borne in mind. Possibly the Author's idea was the same as his own, namely, that if British railways were going to depart once again from their design of permanent way they might as well "go the whole hog" and consider the question of flat-bottom track. Was not that why the Author had been experimenting with flat-bottom track? If a change was to be made he thought that the railways should not limit themselves to anything that had been done in the past. Times were changing and speeds were changing, and undoubtedly trains would have to run better and very much faster after the war than had been the case before the war.

Much had been said about long rails, and the Author had confessed that he was disappointed with the decrease in maintenance costs effected by the use of 120-foot rails. Mr. Train thought, however, that the Author, having regard to the future, and particularly to Mr. Stanier's observations, should take into account the better running given by the long rails. He suggested that in ten years' time the railways would have been forced to eliminate at least 50 per cent. of their joints—perhaps 80 per cent.—and he therefore thought that any experiments which were carried out on the use of long rails were invaluable.

With regard to flat-bottom track, the Author had been good enough to supply him with full details of the results obtained by the London, Midland and Scottish Railway in the use of that track, and he had laid nearly a mile of flat-bottom 110-lb. track in Scotland, which he thought had given the best running in the Scottish area. He would like to ask the Author how long he considered experiments with flat-bottom track would

have to be continued before a decision could be arrived at as to whether it should be adopted or not. That was a very important point.

Vast improvements had been made in flat-bottom track since the days when the British Standards Institution considered the question of the standardization of the permanent way. The elastic spike, which he had used in Scotland, and many other things had been non-existent when flat-bottom track had previously been tried.

**Mr. W. A. Willox** said that the Paper was very welcome to those who for a long time had emphasized the importance of permanent way in the engineering departments of the railways. In the early years of the present century, before the last war, a tendency to neglect the permanent way had existed. Conditions were different then, of course, with regard to loads and speeds, but, whereas the old London and North Western Railway claimed, with some justification perhaps, to have the finest track in the world, that probably applied only to certain features, and a close examination of that track might have shown that other features were sadly neglected. The claim might have been justified with regard to drainage, ballast, and the general standard of maintenance, but with regard to alignment and junction work he thought that the track fell behind such smaller constituents of the present London, Midland and Scottish Railway as the old Glasgow and South Western Railway. Again, on other lines excellent features could be found which on yet other lines were completely neglected. Now at last the whole subject was being reviewed comprehensively, and something really good was being laid down as a standard for all main lines throughout Great Britain.

Despite the increasing attention to permanent way, which had been born of higher speeds and heavier loads, British practice on the whole, he thought, had not kept pace with practice in certain other countries, and a great deal of leeway would have to be made up after the war. The Author's reference to a standard type of joint for wet formations gave a clue to the basic factor of good permanent way. There should not be any wet formation, any more than a wet foundation in a bridge would be tolerated. If one imagined a bridge having to be constantly packed up because the foundations had not been taken down to a solid bottom, one would realize the anomaly of a wet formation to carry not only a very heavy dead load but also a very lively live load. The fact was that half the experiments that had been made in regard to permanent way in the past few decades had their only justification in attempts to overcome the fundamental deficiency of an inadequate foundation. Mr. Willox contended that, with a really adequate foundation throughout, and with proper alignment of curves and junctions, irregular side thrusts could be greatly reduced. There should, however, be much more complete co-operation than hitherto between the various engineering departments on the railways and between the traffic departments and the engineering departments. Eventually the ideal of a uniform speed for all traffic,

which was quite a practical proposition in reality, would impose on properly aligned track vertical loads only, free from lateral thrusts. There would have to be a sufficient depth of ballast to distribute adequately the load to the formation, whatever it might be, in such a way that the formation would bear that load, just as was done in the case of a bridge or other structure. That was the basis of sound permanent way, and it had been recognized, particularly in Germany and America, that, with that sound basis, maintenance could be very largely eliminated. He thought that in Germany, with the provision—which had been consistently imposed during the past fifteen or twenty years—of a minimum of 15 inches of ballast under the sleeper, with a proper foundation, with the ballast thoroughly consolidated, first by rolling and then by pneumatic tamping, and with the type of joint and fastening that was used, the railways had been able to neglect the maintenance of their permanent way without its deterioration. That was a very valuable munition of war in times such as the present. What it had cost the German railways in money did not matter, because they were already bankrupt. It was an important matter which the railways in Great Britain would have to consider; it was quite inevitable, and they should not be deterred by the fact that their difficulties were greater than those encountered abroad. They had a multiplicity of junctions, over-bridges and all kinds of structures, including platforms, but they would have to tackle the problem, and the sooner they tackled it the better.

**Mr. W. G. Dunstan** observed that earlier speakers had been able to regard the subject of the Paper very much from the "top" and look down at it, whereas it was necessary for him to look up at it.

With regard to the question of alignment, particularly of curves, the Author had referred to the fact that some hundreds of curves on his railway had been re-aligned and thousands of stakes had been used in pegging out the new alignment. No doubt the stakes had been put in accurately in the first instance, and probably the permanent way had been laid correctly to them; but, as was well known, when permanent way was laid it was very lively; it did not "stay put" until about three or four months had elapsed. He would like to know what methods were adopted on the London, Midland and Scottish Railway and on other railways to ensure that the track finally came to rest in the desired alignment.

He had assisted in the re-alignment of curves on the London and North Eastern Railway before the introduction of the "Silver Jubilee", and the method adopted was as follows. Wooden stakes were driven and the track was slued to the new line, and almost immediately—at all events as soon as the track had been ballasted—the plate-layers put in the concrete alignment blocks. Then an assistant scratched on the lead strip of the block a mark at a given distance, usually 3 feet, from the outside edge of the rail, the block being in the 6-foot way, and almost simultaneously re-chorded and versined the curve. The assistant then returned

to the office and quickly prepared another Hallade scheme; that could be done much more quickly than the original calculation, because, as the track had been in for only about a week, it had not moved much, at any rate not to as bad a position as that which existed before the sluing took place. Then, using the scratches which had been made on the lead strips of the monument blocks as his datum, he made new marks on the blocks—generally speaking never more than 1 inch in either direction—to indicate the correct alignment. The track was kept to that alignment, being corrected every week, or more often if necessary, until eventually it came to a stand. As the track tended to move, the blocks themselves might possibly move. The blocks used were about 18 inches in depth, and ballast usually existed for the whole of that depth, that was, from the top of the sleeper to about 1 foot beneath, the line often being re-laid with a lift on the top of the old ballast. That ballast was lively, and he knew from experience that the blocks did move. He would like to know whether the Author would consider it better to have, say, every twentieth block a more permanent block, so that the curve could be re-aligned more easily than if the whole process had to be repeated.

Elastic spikes had to be driven down until they just had a bearing on the rail, and then they were driven, he thought, a further $\frac{3}{16}$ inch. How did the men ensure that they drove the spikes in the correct distance? They would have to give them a predetermined blow, or was there something to prevent the spikes going farther down than they should?

**The Chairman** said it was evident that the Author had opened up a very large field of railway research work and practical work in maintaining railways. He hoped that the Railway Engineering Section of The Institution would continue as a very live Section and that many other Papers would be presented for discussion, with, perhaps, an opportunity for further discussion of the various points raised by the Author. He could say without hesitation that no more valuable railway Paper had ever been presented to The Institution or to any other Institution in Great Britain.

**The Author**, in reply, observed that it was quite true, as stated by the Chairman, that hardwood sleepers were not normally an economic proposition in Great Britain, and the use of softwoods with flat-bottom rails would require larger baseplates than those required for hardwoods; but if flat-bottom rails were adopted in Britain, it would be necessary to provide baseplates of adequate size.

He appreciated the points made by Mr. Quartermaine as to the financial comparisons between bull-head and flat-bottom track. Originally he had adopted the 110-lb flat-bottom rail because it had a head approximately equal in area to the 95-lb. R.B.S. rail. In the later tests in 1939, the 131-lb., A.R.E.A. section was adopted because it was standard in the heavy-traffic lines in the Eastern United States, and also, as its base was

the same width as the 110-lb. B.S. flat-bottom rail, additional types of base plates were not required.

As already mentioned, the Author's primary idea in experimenting with flat-bottom track was to reduce maintenance costs; it appeared probable from American experience that that might be attained.

He had put in some 100-lb. bull-head rails of a similar section to that used by Mr. Quartermaine in places where the rail-life was the controlling feature and it was thought that a more balanced life of track as a whole would be obtained in that way, but so far he had been rather disappointed with the results. The rail had worn more rapidly than the 95-lb. rail.

He thought that if a flat-bottom road was adopted it would be found to be more costly, but he had been considerably impressed, when he went to America, at the end of the depression in Great Britain and in the latter half of the depression in the United States, by the way in which the road had stood up to traffic which was fast and heavy in units though not in frequency, with very little maintenance indeed. He considered that the problem to which railway engineers would have to devote most attention after the war, if railways were to be an economic success, was the reduction of the day-to-day maintenance. They would be faced with a permanent increase in rates of pay, and, unless they could maintain the road for a lower cost in hours per mile per annum, they would be at a severe disadvantage in comparison with other forms of transport. Moreover, quite apart from any question of commercial competition, it was the duty of railways to obtain the most efficient track they could, and he wanted to see whether flat-bottom road would be more economical from the point of view of maintenance.

He appreciated Mr. Train's question as to how long the experiments with flat-bottom track should be continued, but it was an extremely difficult question to answer. The outbreak of the war had undoubtedly postponed a definite answer, and it would probably be necessary to lay further milage of flat-bottom track in continuous lengths to get definite figures of savings in maintenance.

Mr. Train had raised an interesting point with regard to the 120-foot rail giving better running. The Author agreed that the running was a little quieter, but, speaking frankly, he had been very much disappointed at the differential which the steel trade put on that rail. If railways were going to be charged too much for long rails they would either have to give up the idea of using them or, alternatively, have to weld them. It was a question of economics, and so far the steel trade seemed to be rather anxious that he should have the rails welded.

Mr. Willox's remarks on the necessity for a sufficient depth of ballast were very sound, but it would be extremely difficult to obtain that in many instances in Great Britain owing to the restricted clearance of the frequent overbridges.

Mr. Willox had revealed a silver lining to the cloud when he pointed

out that it did not matter what the German railways spent on their track as they were bankrupt anyhow. If the road transport people did all that they said they were going to do after the war the British railways would have a good time, because they also would be bankrupt and then they would have plenty of money to spend!

The Author had hoped to have run a control test with pneumatic tamping of flat-bottom road, with the idea of reducing maintenance expenditure.

Vehicle hunting on newly laid track would be largely cured if the Mechanical Engineers adopted a flatter coning of tires. The film shown by Mr. Stanier during his Presidential Address to the Institution of Mechanical Engineers [1] was very convincing on that point.

The Author believed that objectionable hunting of rolling stock would be cured by altering the coning of the wheels rather than the radius of the rail-head.

Mr. Stanier's remarks about the reaction of joint shock on the maintenance of rolling stock were very interesting, and it would be a great help to the Permanent Way Engineer if the Mechanical Engineers could quantify the savings they would make if long rails were adopted as standard.

He was interested in Mr. Dunstan's remarks about concrete pegs. The pegs which his Company used were 2 feet long, and they were put in shortly after the road was pulled to the new alignment. They were not permanently marked till in situ about 3 weeks. So far he had not had to move enough pegs to make it worth while to put in a more permanent monument at regular intervals, as Mr. Dunstan had suggested. The line was run over by the Hallade instrument once a year, and attention was given to any curve which looked like giving bad results.

With regard to driving in the elastic spikes, the men very soon got to know the force of the blow required to drive them in to the correct depth, and a gauge was used as a check.

It was a great pleasure to him to see such a large gathering, and he thanked the speakers for the flattering remarks they had made about his Paper. The comments which had been made upon it were very gratifying to him, as they would be also to all those who had helped him to prepare it. He hoped the Paper would be only the first of a long series and that the Chairman's problem would be to choose between the Papers submitted, and not to persuade people to write them.

[1] Proc. Inst. Mech.E., vol. 146, p. 50 (Dec. 1941).

Table I.—Spreading of Gauge on Curves. Tests of Screwed Standard and Bolted Chairs.

| Locality. | Road. | Gradient. | Curve: chains. | Cant: inches. | Date laid. | Date last inspected. | Trains per day. | | Average speed. | | Chairs showing spread: per cent. | | | Maximum widening of gauge. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pass. | Goods. | Pass. M.p.h. | Goods. M.p.h. | L.M.S. standard. | G.W. | L.M.S through-bolted. | L.M.S. standard. | G.W. | L.M.S. through-bolted. |
| St. Albans . . | Down fast | 1 in 285 Up | 70 | 2½ | 25.2.35 | 17.11.41 | 51 | 14 | 55 | 35 | 51·52 | 22·23 | 6·76 | 0·140 | 0·136 | 0·118 |
| Govilon . . . | Up | 1 in 38 Down | 11 | 4½ | 13.9.34 | 1.7.41 | 11 | 8 | 20 | 15 | 68·64 | 93·53 | | 0·292 | 0·332 | — (1) |
| Lancaster . . | Down | 1 in 98 ,, | 28 | — | 10.12.34 | 29.3.38 | 42 | 38 | 52 | 31 | 66·47 | 21·53 | — | 0·579 | 0·376 | — (2) |
| Tebay . . . | Up | 1 in 146 ,, | 62 | 4¾ | 16.3.35 | 1.8.41 | 30 | 25 | 60 | 34 | 42·86 | — | 4·91 | 0·276 | — | 0·116 |
| | | | 76 | 3¾ | | | | | | | | | | | | |
| | | | 76 | 3¾ | | | | | | | | | | | | |
| Milnthorpe . . | Up | 1 in 173 ,, | 70 L.H. | 2½ | 10.3.35 | 28.7.41 | 38 | 28 | 60 | 34 | 40·5 | 3·99 | 18·72 | 0·412 | 0·077 | 0·236 (3) |
| | | | 75 ,, | 2½ | | | | | | | | | | | | |
| | | | 53 ,, | 3½ | | | | | | | | | | | | |
| | | | 49 R.H. | 3½ | | | | | | | | | | | | |
| Great Glen . . | Down | 1 in 298 ,, | 160 | 2¼ | 13.2.35 | 21.5.41 | 40 | 40 | 55 | 35 | 30·31 | — | 0·71 | 0·033 | — | 0·041 |
| Berkhamsted . | Up fast | 1 in 335 ,, | 200 R.H. | 1½ | 26.3.35 | 20.10.41 | 70 | 19 | 65 | 49 | 73·91 | 31·66 | 46·13 | 0·238 | 0·124 | 0·272 |
| | | | 162 ,, | 2⅛ | | | | | | | | | | | | |
| | | | 56 L.H. | 4⅛ | | | | | | | | | | | | |
| Weaver Junction | Down | 1 in 330 Up | 120 | 1¾ | 4.4.35 | 13.9.38 | 36 | 21 | 50 | 31 | 1·94 | — | 5·75 | 0·064 | — | 0·041 (4) |
| | | | 75 to 160 | 2¾–1½ | | | | | | | | | | | | |
| | | | 75 | 2¾ | | | | | | | | | | | | |
| Leighton Buzzard | Down fast | 1 in 927 Down | 60 | 4¾ | 23.4.35 | 25.8.41 | 57 | 20 | 65 | 36 | 68·22 | — | 86·79 | 0·175 | — | 0·215 (5) |

Notes:—

(1) L.M.S. Standard reset to gauge, 3.3.38.
(2) L.M.S. Standard reset to gauge three times, first 16.9.35; 48 sleepers relaid 17.5.38.
(3) General spread in 1940 owing to slow running during air raids. Road regauged in 1940.
(4) L.M.S. Standard—probably reset to gauge in 1937.
(5) General spread in 1940 owing to slow running during air raids. Road regauged in 1940.

TABLE II.—RESISTANCE TO LATERAL LOADING.

| Type of assembly. | Type of chairs. | Details of fastenings. | Height of screws. | Felt pads used. | Spread of gauge: inches with 10-ton horizontal load. |
|---|---|---|---|---|---|
| L.M.S. 2-bolt . . . . . . . | A.S.I.A. plain base | 2 bolts, $\frac{7}{8}$ inch diameter | — | No | 0·405 |
| L.N.E. 3-bolt . . . . . . . | L.N.E. S.1B. | 3 bolts, $\frac{7}{8}$ inch diameter (2 inside, 1 outside) | — | ,, | 0·4425 |
| G.W. 2-bolt . . . . . . . . | G.W. Standard serrated base | 2 bolts, $\frac{7}{8}$ inch diameter | — | ,, | 0·453 |
| L.M.S. 2-bolt chairs with underside projections | B.S.1, with underside projections | 2 bolts, $\frac{7}{8}$ inch diameter staggered $\frac{1}{2}$ inch off centre line | — | ,, | 0·53 |
| L.M.S. 3 screws, standard without felt pads | A.S.I. Standard | 3 standard screws (2 inside, 1 outside) | Correct | ,, | 0·386 |
| L.M.S. 3 screws, standard . . . | ,, ,, | ,, ,, | ,, | Yes | 1·382 |
| L.M.S. 3 screws, chairs with underside projections | A.S.1 with underside projections (as type B.S.I.) | ,, ,, | ,, | No | 0·386 * |
| L.M.S. 3 screws . . . . . . | R.S.1 | 3 standard screws (1 inside, 2 outside) | As left by screwing machine | Yes | 1·359 |
| L.M.S. 110-lb. flat-bottom rail and elastic spikes | Baseplates | 3 double-leaf spikes driven into $\frac{19}{32}$-inch holes (1 inside, 2 outside) | — | No | 1·02 |
| L.M.S. 110-lb. flat-bottom rail and elastic spikes | ,, | 3 double-leaf spikes driven into $\frac{1}{2}$-inch holes (1 inside, 2 outside) | — | ,, | 0·527 |

* Jaw broke at 9·25 tons load.

TABLE III.—TESTS OF FLAT-BOTTOM RAILS, 1936.

Results to 15th June 1941.

| District. | Reference number. | Mileage. | | Line. | Type. | Numbers of sleepers. | Period: weeks. | Ratios. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Miles. | Yards. | | | | | Packing. Middles. | Packing. Joints. | Packing. Total. | Lining. | Fish-bolts. | Fastenings: Plate or chair. | Total. |
| 1. | 2. | 3. | | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. |
| London . . | A.1 | 4 | 30 | Down fast | R.B.S. | 24 | 229 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, . . | A.2 | to | | ,, ,, | Williams' Elastic Spike | 29 | 217 | 73 | 83 | 79 | 101 | 267 | 61 | 88 |
| ,, . . | A.3 | 4 | 910 | ,, ,, | ,, American | 29 | 217 | 141 | 122 | 130 | 105 | 259 | 100 | 159 |
| London . . | B.1 | 4 | 1,232 | Up fast | Williams' German | 24 | 229 | 65 | 61 | 64 | 49 | 113 | 67 | 77 |
| ,, . . | B.2 | to | | ,, ,, | R.B.S. | 24 | 229 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, . . | B.3 | | | ,, ,, | Colvilles' German | 29 | Record discontinued; road destroyed by enemy action, Nov. 1940 | | | | | | | |
| ,, . . | B.4 | 5 | 880 | ,, ,, | ,, ,, | 24 | 221 | 73 | 53 | 67 | 64 | 113 | 1,500 | 80 |
| London . . | C.1 | 8 | 1,719 | Down fast | Colvilles' German | 29 | 217 | 230 | 119 | 195 | 161 | 377 | 297 | 221 |
| ,, . . | C.2 | to | | ,, ,, | ,, ,, | 24 | 217 | 211 | 116 | 182 | 167 | 419 | 330 | 225 |
| ,, . . | C.3 | 9 | 737 | ,, ,, | R.B.S. | 24 | 217 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| London . . | D.1 | | | Up passenger | Williams' Elastic Spike | 24 | 217 | 83 | 90 | 85 | 55 | 56 | 279 | 81 |
| ,, . . | D.2 | 35 | 1,476 | ,, ,, | ,, American | 24 | 217 | 100 | 104 | 101 | 68 | 66 | 75 | 97 |
| ,, . . | D.3 | to | | ,, ,, | ,, German | 29 | 221 | 86 | 84 | 86 | 60 | 59 | 79 | 128 |
| ,, . . | D.4 | 36 | 1,735 | ,, ,, | ,, ,, | 24 | 221 | 96 | 94 | 95 | 62 | 60 | 46 | 127 |
| ,, . . | D.5 | | | ,, ,, | R.B.S. | 24 | 221 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Derby, South | E.1 | | | Down passenger | R.B.S. | 24 | 229 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, ,, | E.2 | 100 | 390 | ,, ,, | Williams' German | 29 | 229 | 34 | 52 | 42 | 30 | 111 | 29 | 120 |
| ,, ,, | E.3 | to | | ,, ,, | ,, ,, | 24 | 229 | 46 | 52 | 48 | 40 | 118 | 41 | 118 |
| ,, ,, | E.4 | 101 | 897 | ,, ,, | Taylor Bros. C.I. American | 29 | 225 | 6 | 35 | 18 | 8 | 62 | — | 38 |
| ,, ,, | E.5 | | | ,, ,, | ,, ,, ,, | 24 | 225 | 56 | 21 | 41 | 20 | 62 | — | 56 |
| Derby, South | F.1 | 116 | 1,126 | Up passenger | Colvilles' German | 29 | 229 | 163 | 245 | 178 | 310 | 62 | - | 288 |
| ,, ,, | F.2 | to | | ,, ,, | ,, ,, | 24 | 229 | 97 | 160 | 109 | 283 | 64 | | 207 |
| ,, ,, | F.3 | 117 | 666 | ,, ,, | R.B.S. | 24 | 229 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| South Eastern | G.1 | | | Down | R.B.S. | 24 | 243 | — | — | — | — | — | — | — |
| ,, ,, | G.2 | 29 | 430 | ,, | Colvilles' German | 29 | 208 | 47 | 41 | 45 | 23 | 100 | 50 | 49 |
| ,, ,, | G.3 | to | | ,, | ,, ,, | 24 | 208 | 84 | 75 | 81 | 36 | 100 | 1,250 | 86 |
| ,, ,, | G.4 | 31 | 430 | ,, | Williams' American | 29 | 194 | 194 | 170 | 184 | 62 | 600 | — | 185 |
| ,, ,, | G.5 | | | ,, | ,, ,, | 24 | 194 | 118 | 118 | 118 | 43 | 40 | — | 117 |
| ,, ,, | G.6 | | | ,, | R.B.S. | 25 | 243 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

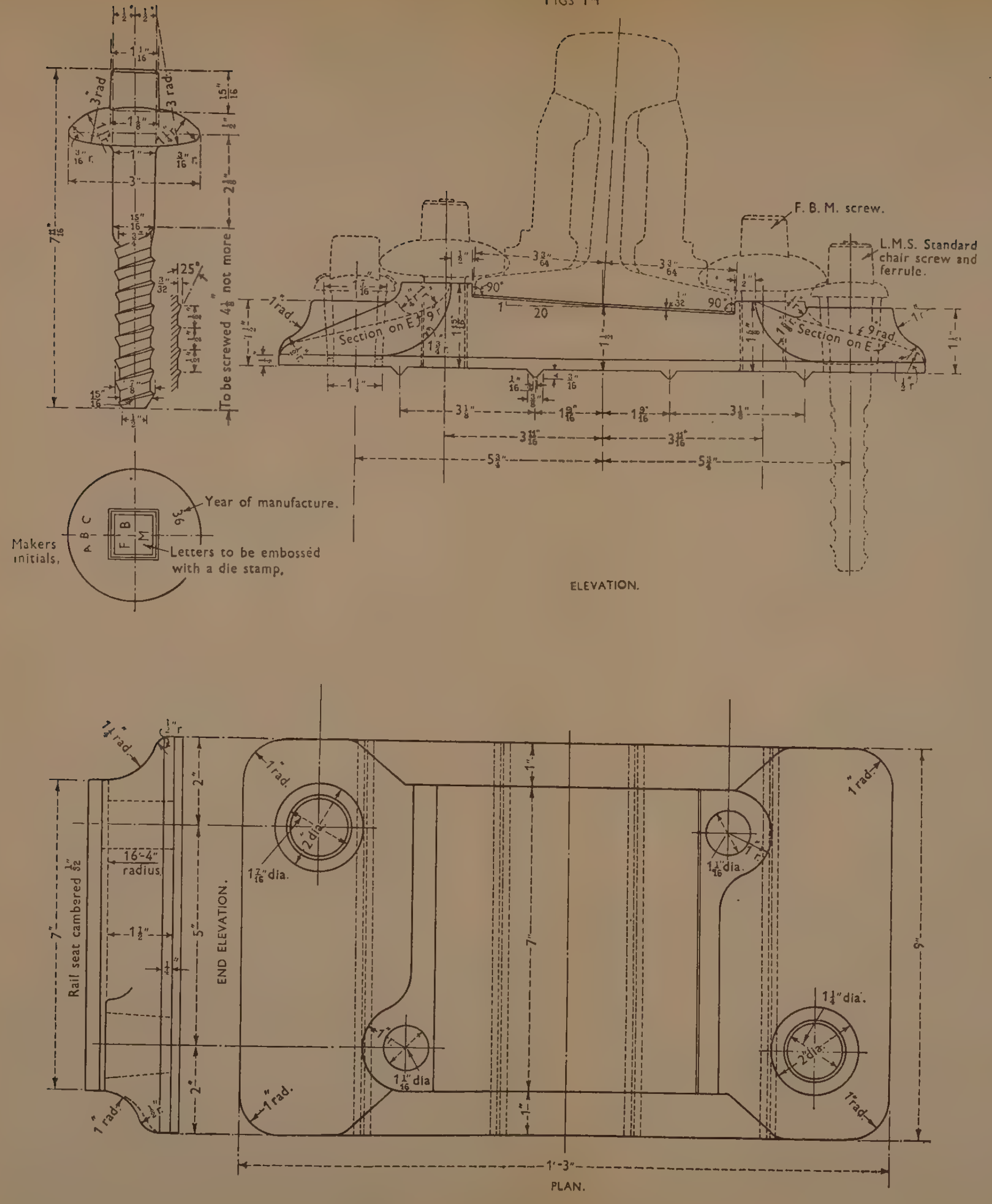
TABLE IV.—TESTS OF FLAT-BOTTOM RAILS, 1939.

Results to 13th July 1941.

| District. | Ref. | Milage. Miles. | Yards. | Line. | Type. | Number of sleepers. | Period: weeks. | Ratios. Packing. Middles. | Joints. | Total. | Lining. | Fish-plates. | Fish-bolts. | Fastenings (inc. keys). | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. |
| Watford | A.1 | 24 | 1,334 | Down fast | 110-lb. F.B. Steel Plate. Elastic Spike | 24 | 92 | 104 | 131 | 105 | 145 | 125 | 336 | 178 | 138 |
| ,, | A.2 | to | | ,, ,, | 110-lb. F.B. C.I. Plate. Elastic Spike | 24 | 92 | 125 | 181 | 128 | 127 | 107 | 58 | 233 | 140 |
| ,, | A.3 | 26 | 67 | ,, ,, | 110-lb. F.B. C.I. Plate. Clips and Screws | 24 | 96 | 70 | 44 | 69 | 67 | 93 | 76 | 174 | 89 |
| ,, | A.4 | | | ,, ,, | R.B.S. | 24 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Watford | B.1 | 64 | 1,758 | Up | 131-lb. F.B. Steel Plate. Elastic Spike | 24 | 72 | 148 | 168 | 152 | 178 | 336 | 172 | 164 | 168 |
| ,, | B.2 | to | | ,, | 131-lb. F.B. C.I. Plate. Elastic Spike. | 24 | 72 | 122 | 105 | 119 | 80 | 188 | 120 | 152 | 125 |
| ,, | B.3 | 66 | 451 | ,, | 131-lb. F.B. C.I. Plate. Clips and Screws | 24 | 72 | 112 | 91 | 107 | 80 | 152 | 89 | 240 | 136 |
| ,, | B.4 | | | ,, | R.B.S. | 24 | 72 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Watford | C.1 | 68 | 763 | Down | R.B.S. | 26 | 92 | — | — | — | — | — | — | 98 | — |
| ,, | C.2 | to | | ,, | 110-lb. F.B. Steel Plate. Elastic Spike | 26 | 92 | 117 | 79 | 106 | 77 | 89 | 3 | 57 | 60 |
| ,, | C.3 | 69 | 630 | ,, | 110-lb. F.B. C.I. Plate. Elastic Spike | 26 | 92 | 83 | 69 | 79 | 73 | 108 | 2 | 74 | 51 |
| ,, | C.4 | | | ,, | R.B.S. | 26 | 92 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Watford | *D.1 | 68 | 826 | Up | 131-lb. F.B. Steel Plate. Elastic Spike | 26 | 100 | 103 | 81 | 98 | 83 | 135 | 21 | 90 | 91 |
| ,, | *D.2 | to | | ,, | 131-lb. F.B. C.I. Plate. Elastic Spike | 26 | 100 | 81 | 70 | 78 | 79 | 106 | 45 | 54 | 72 |
| ,, | *D.3 | 69 | 679 | ,, | 131-lb. F.B. C.I. Plate. Clips and Screws | 26 | 100 | 90 | 73 | 86 | 75 | 106 | 48 | 236 | 107 |
| ,, | D.4 | | | ,, | R.B.S. | 26 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Crewe | E.1 | 146 | 20 | Up fast | 110-lb. F.B. C.I. Plate. Elastic Spike | 26 | 68 | 159 | 135 | 152 | 41 | 118 | 88 | — | 140 |
| ,, | E.2 | to | | ,, ,, | 110-lb. B.F. C.I. Plate. Clips and Screws | 26 | 68 | 162 | 187 | 170 | 34 | 112 | 100 | — | 156 |
| ,, | E.3 | 147 | 220 | ,, ,, | 131-lb. F.B. Steel Plate. Elastic Spike | 26 | 68 | 141 | 199 | 159 | 37 | 358 | 93 | — | 148 |
| ,, | E.4 | | | ,, ,, | 131-lb. F.B. C.I. Plate. Clips and Screws | 26 | 68 | 73 | 115 | 87 | 42 | 245 | 100 | — | 109 |
| ,, | E.5 | | | ,, ,, | R.B.S. | 26 | 68 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Crewe | F.1 | 148 | 893 | Down fast | 110-lb. F.B. C.I. Plate. Elastic Spike | 26 | 72 | 133 | 75 | 124 | 16 | 181 | 331 | — | 139 |
| ,, | F.2 | to | | ,, ,, | 110-lb. F.B. C.I. Plate. Clips and Screws | 26 | 72 | 159 | 124 | 153 | 179 | 176 | 310 | | 175 |
| ,, | F.3 | 149 | 1,507 | ,, ,, | 131-lb. F.B. Steel Plate. Elastic Spike | 24 | 72 | 84 | 110 | 88 | 353 | 271 | 110 | | 110 |
| ,, | F.4 | | | ,, ,, | 131-lb. F.B. C.I. Plate. Clips and Screws | 24 | 72 | 120 | 178 | 130 | 295 | 238 | 90 | — | 175 |
| ,, | F.5 | | | ,, ,, | R.B.S. | 24 | 72 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Liverpool | G.1 | 35 to 36 | 1,320 to 164 | Up fast | R.B.S. | 26 | 36 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, | G.2 | 35 | 1,323 | ,, ,, | 110-lb. F.B. C.I. Plate. Clips and Screws | 26 | 36 | 88 | 82 | 86 | 47 | 135 | — | — | 87 |
| ,, | G.3 | to | | Down fast | R.B.S. | 26 | 36 | 100 | 100 | 100 | 100 | 100 | — | — | 100 |
| ,, | G.4 | 36 | 164 | ,, ,, | 110-lb. F.B. Steel Plate. Elastic Spikes | 26 | 36 | 22 | 38 | 29 | 46 | 132 | — | — | 41 |
| North Wales | H.1 | 199 | 1,320 | Up fast | R.B.S. | 26 | 104 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, ,, | H.2 | to | | ,, ,, | 110-lb. F.B. C.I. Plate. Elastic Spikes | 26 | 104 | 150 | 96 | 131 | 57 | 131 | 145 | 46 | 126 |
| ,, ,, | H.3 | 201 | 440 | ,, ,, | 110-lb. F.B. C.I. Plate. Clips and Screws | 26 | 104 | 200 | 141 | 180 | 57 | 128 | 127 | 141 | 177 |
| ,, ,, | H.4 | | | ,, ,, | R.B.S. | 26 | 104 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Derby, North | J.1 | 151 | 697 | Up | R.B.S. | 26 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, ,, | *J.2 | 152 | 925 | ,, | 131-lb. F.B. Steel Plate. Elastic Spikes | 26 | 96 | 51 | 55 | 52 | 63 | 104 | 62 | 81 | 58 |
| Northampton | K.1 | | | Up passenger | R.B.S. | 24 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, | K.2 | 66 | 533 | ,, ,, | 110-lb. F.B. Steel Plate. Elastic Spike | 24 | 96 | 120 | 98 | 118 | 119 | 111 | 86 | 13 | 115 |
| ,, | K.3 | to | | ,, ,, | 110-lb. F.B. C.I. Plate. Clips and Screws | 24 | 96 | 124 | 99 | 122 | 154 | 112 | 71 | 258 | 124 |
| ,, | K.4 | 67 | 880 | ,, ,, | 131-lb. F.B. Steel Plate. Elastic Spike | 24 | 96 | 115 | 72 | 110 | 115 | 334 | 78 | — | 124 |
| ,, | K.5 | | | ,, ,, | 131-lb. F.B. C.I. Plate. Elastic Spike | 24 | 96 | 108 | 102 | 107 | 31 | 170 | 593 | 374 | 123 |
| ,, | K.6 | | | ,, ,, | R.B.S. | 24 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Stoke | L.1 | 3 | 1,333 | Down | 110-lb. F.B. Steel Plate. Elastic Spikes | 26 | 72 | 87 | 100 | 87 | — | 89 | — | — | 88 |
| ,, | L.2 | to | | ,, | 110-lb. F.B. C.I. Plate. Elastic Spikes | 26 | 72 | 69 | 81 | 69 | — | 89 | — | — | 70 |
| ,, | L.3 | 4 | 1,319 | ,, | R.B.S. | 26 | 72 | 100 | 100 | 100 | — | 100 | — | — | 100 |
| Lancaster | M.1 | 13 | 880 | — | R.B.S. | 26 | 92 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| ,, | M.2 | to | | | 110-lb. F.B. Steel Plate. Elastic Spikes | 24 | 92 | 65 | 63 | 64 | 98 | 224 | 128 | 67 | 69 |
| ,, | M.3 | 14 | 732 | — | 110-lb. F.B. C.I. Plate. Elastic Spikes | 24 | 92 | 87 | 79 | 85 | 117 | 198 | 117 | 54 | 82 |
| Lancaster | *N.1 | 18 | 173 | Down | 131-lb. F.B. Steel Plate. Elastic Spikes | 24 | 84 | 208 | 67 | 182 | — | 246 | — | — | 304 |
| ,, | *N.2 | to | | ,, | 131-lb. F.B. C.I. Plate. Elastic Spikes | 24 | 84 | 198 | 82 | 177 | — | 243 | — | — | 234 |
| ,, | *N.3 | 19 | 475 | ,, | 131-lb. F.B. C.I. Plate. Clips and Screws. | 24 | 84 | 264 | 134 | 240 | — | 163 | — | — | 242 |
| ,, | N.4 | | | ,, | R.B.S. | 24 | 84 | 100 | 100 | 100 | — | 100 | — | — | 100 |

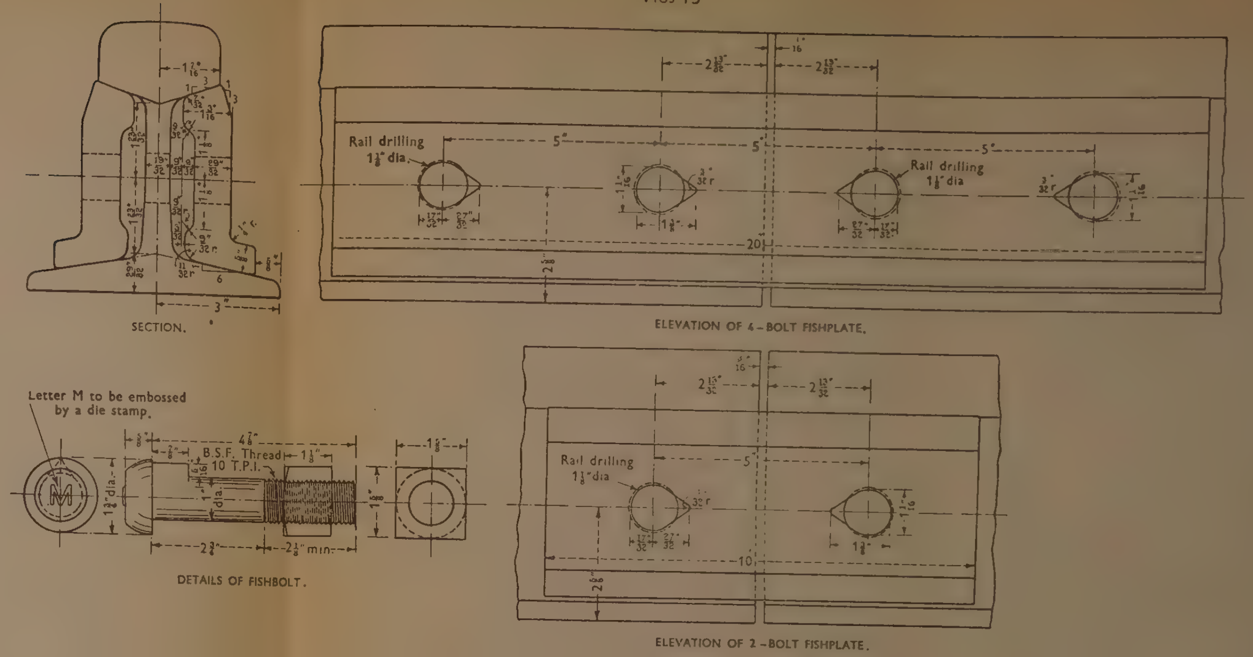
NOTE. * denotes Sorbitic rail.

Figs 14




CAST IRON BASEPLATE FOR USE WITH 110 LB. PER YARD FLAT BOTTOM RAIL.

Figs 15




FISHPLATES AND BOLTS FOR 110 LB. FLAT BOTTOM RAIL.

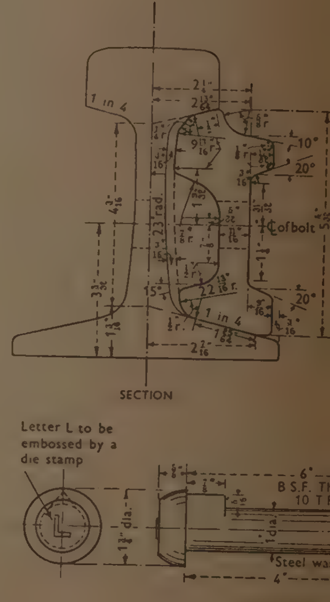
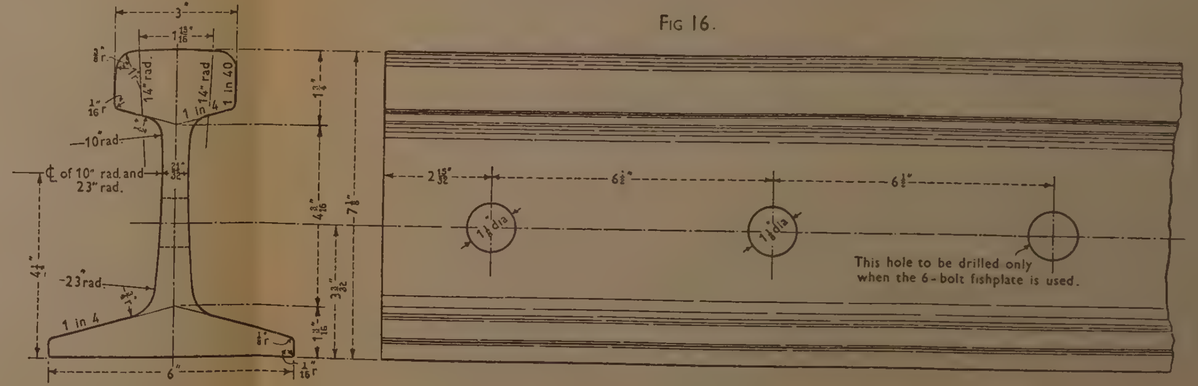


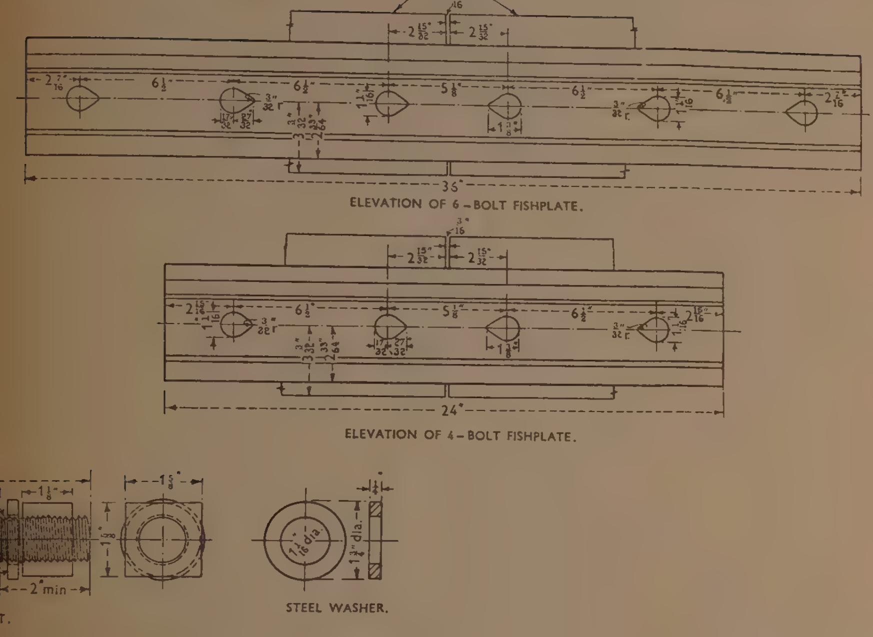

Fig 16.




AMERICAN FLAT BOTTOM RAIL 130·8 LB PER YARD. SECTION AND DETAILS OF RAIL DRILLING.

William Clowes & Sons, Limited: London.

Figs 17.



ELEVATION OF 6-BOLT FISHPLATE.

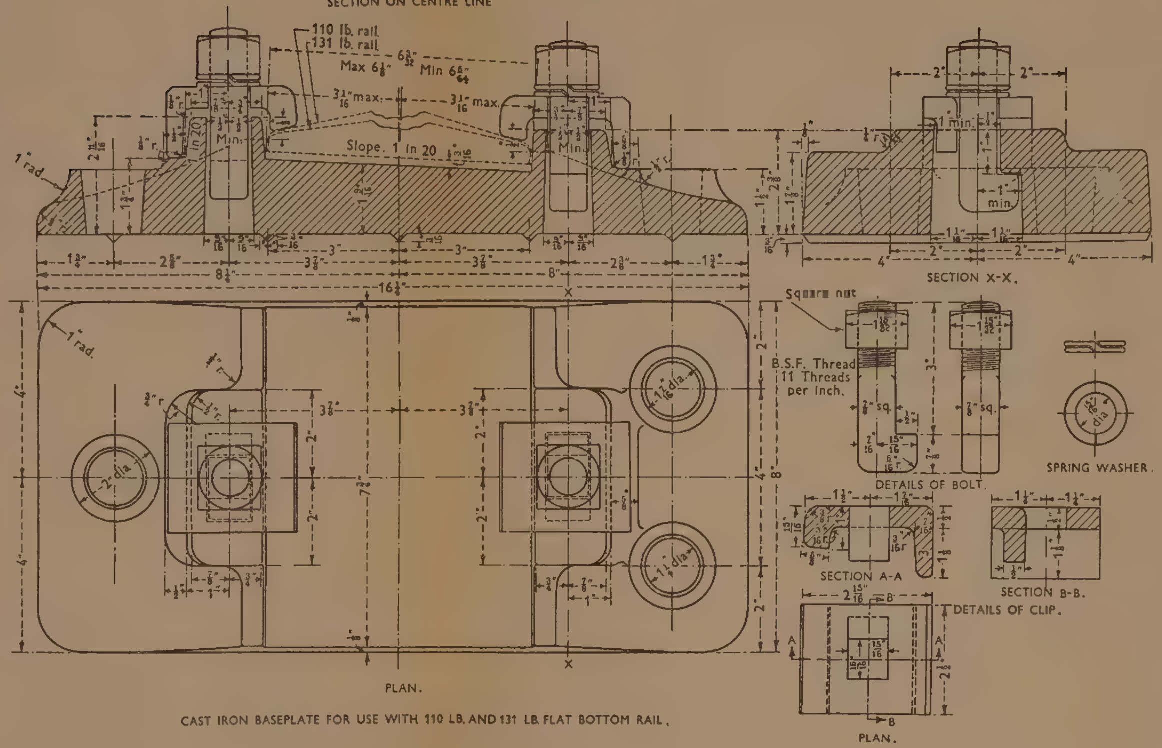
ELEVATION OF 4-BOLT FISHPLATE.

STEEL WASHER.

FISHPLATES AND BOLTS FOR 131 LB. AMERICAN FLAT BOTTOM RAIL.

Fig 18.

SECTION ON CENTRE LINE



SECTION X-X.

DETAILS OF BOLT.

SPRING WASHER.

SECTION A-A

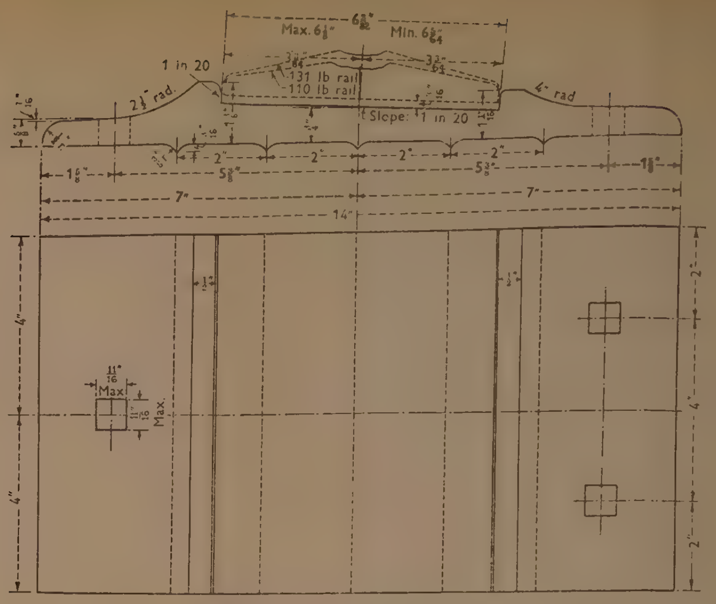
SECTION B-B.

DETAILS OF CLIP.

PLAN.

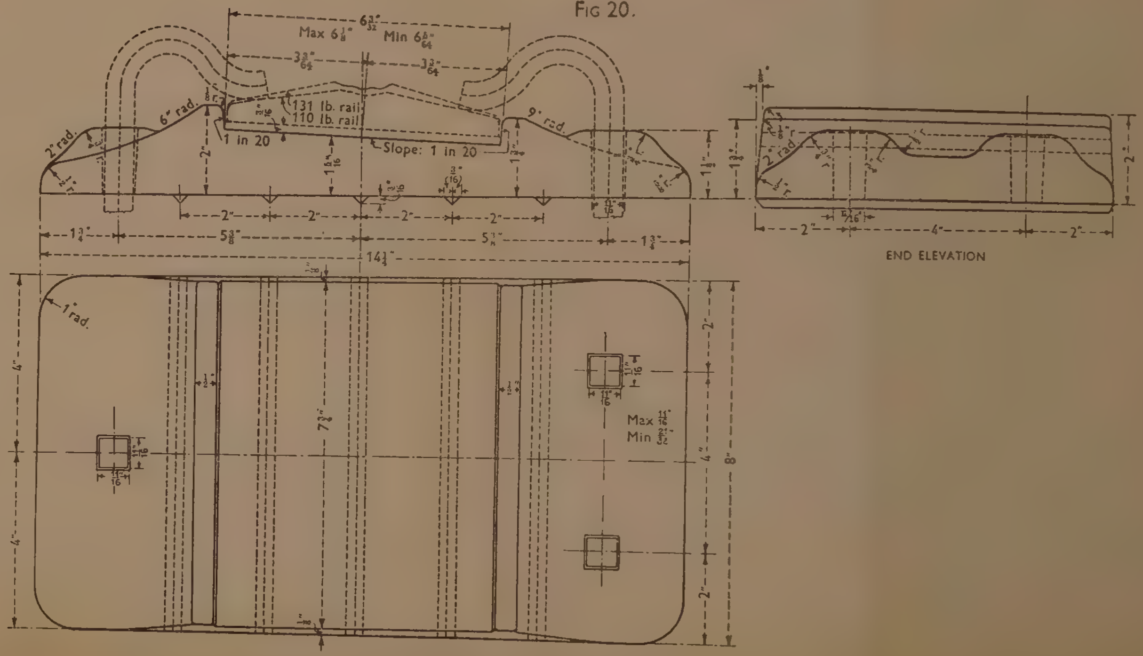
CAST IRON BASEPLATE FOR USE WITH 110 LB. AND 131 LB. FLAT BOTTOM RAIL.

Fig. 19



STEEL BASEPLATE FOR USE WITH ELASTIC RAIL SPIKES
110 LB. AND 131 LB. FLAT BOTTOM RAILS.

Fig 20.



END ELEVATION

CAST IRON BASEPLATE FOR USE WITH ELASTIC RAIL SPIKES 110 LB. AND 131 LB. FLAT BOTTOM RAIL.

## ORDINARY MEETING.

10 February 1942.

Professor CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S., President, in the Chair.

Discussion on

# "Soil Mechanics and Site Exploration." [1]

and on

# "Soil Mechanics in Road and Aerodrome Construction." [2]

**Mr. Cooling,** in introducing his Paper, said that the subject of site exploration was one which had always been of prime practical importance to the engineer concerned with the design of foundations and earthworks. The knowledge of soils and soil behaviour which had been rendered available during recent years by the science of soil mechanics could be of such practical assistance to the engineer that it should be more widely known and appreciated.

In his brief description of sounding methods, in the advance proof of his Paper, he had referred to a Paper by Mr. G. B. R. Pimm, M. Inst. C.E. It had been pointed out that the description was not an accurate account of Mr. Pimm's method, and the footnote reference would therefore be deleted from the Paper as published in the Journal. There was no doubt that, with a sufficient background of experience, methods of that type could furnish valuable data in particular cases.

He would like to add a little to what he had said in the Paper about the contributions which soil mechanics could bring to the consideration of practical problems, particularly with regard to site exploration. For convenience, those contributions could be considered under four main headings: (1) recognition of soil types; (2) mechanical properties and tests; (3) theoretical methods of analysis; and (4) systematic collection of data.

With regard to the recognition of soil types, in the preliminary examination of a site a knowledge of geology was often very helpful. Much depended upon the judgement of the engineer in recognizing types of

[1] L. F. Cooling, "Soil Mechanics and Site Exploration," Journal Inst. C.E., vol. 18 (1941–42), p. 37 (Mar. 1942).

[2] A. H. D. Markwick, "Soil Mechanics in Road and Aerodrome Construction," Journal Inst. C.E., vol. 18 (1941–42), p. 62 (Mar. 1942).

soil which were likely to cause trouble. Soil mechanics could give valuable assistance in that connexion, and would probably be more helpful as the volume of data increased. For that purpose very simple tests—the "index-property" tests—such as natural water-content, liquid limit, and compressive strength, had been found by him to be very useful. They could be easily carried out and yielded quantitative results which indicated soil type and consistency.

A knowledge of the mechanical properties of soils was useful from the point of view of site exploration, in enabling the value of samples which were obtained by various methods of boring to be assessed and in aiding recognition of site conditions which might have an important influence upon a particular problem. A study of the mechanical properties also brought out the important influence of the water in the pores of a soil in modifying the mechanical behaviour. That pointed to the need for making, during boring, observations of ground-water levels and of the pressure in the water at the various levels, and also for noting and recording the position of permeable strata through which water could move readily. Tests on soils in general were, of course, obviously important, especially when the results were used for purposes of analysis.

Theoretical methods of analysis were available, using measured values of soil characteristics, and they served for the consideration of most of the important problems of foundation engineering; but from the point of view of site exploration their main importance was that they gave an insight into the probable behaviour of the soil and so indicated the kind of information which was required for the study of a practical problem. For that reason he had devoted a substantial part of the Paper to a description of investigations made in connexion with specific practical problems. It was true that all the problems he had dealt with were of one type, that was, they were concerned with the stability of footings and earthworks, but it was not possible to include in a short Paper all the various problems which came within the scope of soil mechanics.

The systematic collection of data by soil mechanics methods was an aspect of considerable importance in the development of a subject which was comparatively new. The methods of soil mechanics laid stress on quantitative measurements for recording the behaviour of structures (for example, settlement readings, pressure measurements, etc.) and also on quantitative measurements for expressing soil properties, and, by so doing, they enabled an individual to gain advantage from the practical experience of others.

Most of the examples given in the Paper were concerned with failures, but he thought it would be agreed that the thorough examination of failures was a means of obtaining very valuable information.

**Mr. Markwick** said that he wished to make his introductory remarks complementary to those of Mr. Cooling, so far as possible. He showed a series of lantern slides, and observed that one of the first problems which

had to be faced when the engineering properties of soils began to be seriously studied was to find quantitative methods of classifying soils. Soil consisted mainly of fine mineral particles and water, and many common soils, for instance, clays, were much finer than Portland cement. Standard tests had been evolved and considerable progress had been made in relating their results to the engineering behaviour of the soil.

He wished to refer briefly to the methods of carrying out soil surveys. There had been a good deal of development in that respect during recent years. The Road Research Laboratory used very simple tools for the soil investigations that it carried out, namely, a 5-inch auger, a 4-inch auger and a special kind of auger known as a gravel auger, which was used in stony ground. A great deal of work could be done with very simple tools of that kind, without having to employ the more complicated and difficult technique of lined borings.

In addition to providing an inventory of soil types, information on the natural drainage of the site could often be obtained from the ground-water levels.

From whatever aspect the bearing capacity of the soil was considered, adequate drainage was essential to prevent water from entering the soil and causing it to soften. In draining an aerodrome, the object was to remove surplus water before it had had an opportunity to enter the pores of the soil. That which entered the soil had to be dealt with by natural or by subsoil drainage and might travel either through the pores of the soil or through cracks and fissures. In a relatively pervioüs soil the water would percolate down to the water-table through the pores of the soil, and it had been shown by experiment that the water-table took the form shown in *Fig. 8*, p. 57, *ante*. Dr. Keen, of Rothamsted, had, however, pointed out to him that in stiff clays, which were relatively impervious, most of the soil water probably found its way to the subsoil drains through cracks and fissures in the clay. The importance of that lay in the fact that such water was still mainly "free", that was, it was not bound to the soil particles by capillary suction, so that it was capable of flowing into any drain which was suitably placed, without necessarily having to travel to the water-table level. To that extent, therefore, he would like to qualify the statement made in the Paper that subsoil drains could be effective only when they were at or below the water-table level, although it remained true that capillary water in the pores of the soil could not be removed by drains which were above the water-table level.

He wished to refer briefly to soil compaction in relation to embankment construction. The most important facts to note were the following. Firstly, the degree of compaction could be readily determined both in the field and in the laboratory and was measured by the weight of soil particles per cubic foot. Secondly, for a given mechanical effort there was in general an optimum moisture-content at which maximum compaction was obtained. Thirdly, for cohesive soils the limits to compaction were the

mechanical resistance of the soil for low moisture-contents (when the soil was stiff) and the moisture-content of the soil at high moisture-contents (when the soil was soft), since compaction only forced the air out of the soil.

The study of soil problems in road and aerodrome construction was still a young science, in which there was a great deal to be learned, but he hoped it would be considered that, at any rate, a promising start had been made.

**Professor R. G. H. Clements** observed that the difficulty in soil mechanics was partly due to the terminology which was growing up around the subject. That terminology rather tended to put it out of sight of the practising engineer, whereas it was really a subject which ought to come more and more within his purview and form a day-to-day tool for use in constructional work. It was, in fact, a recognition in principle of the fact that the soil itself was an agent in the construction. Therefore all aspects of soil mechanics were important, but the engineer was most concerned with the one that he could take into everyday life and practice and provide an answer to his problems rapidly and simply.

The technique of soil mechanics had grown up on extremely elaborate lines. The mechanical tests referred to by Mr. Cooling numbered about twenty, but in the long run most of the information required was obtained from the liquid limit, the plastic limit, and, in another connexion, the compression test. A clear distinction should be made between the conditions which were related to research and to the examination of a scientific problem or a field of science and the conditions relating to the ready assessability of methods of test which would serve engineers easily and readily. As an example, tests could be carried out to establish the character of the soil in an undisturbed condition, and could be recorded and used as a guide to the method of consolidation to be adopted and the extent to which that consolidation should go before the soil could be considered as suitable for the construction of the embankment. Further tests could then be carried out on the embankment, as consolidated, to establish the extent to which the specification limits of consolidation had been attained; that was, the extent to which the soil had attained its original undisturbed state of compaction. That might appear to be a counsel of perfection, but it was, in fact, a practice which was followed, and he believed that the standard of compaction accepted for certain classes of embankment work was 80 per cent. of the compaction of the soil in its original state. Whatever that percentage might be, at least there was a direct and definite connexion between the soil test of the undisturbed sample and the test applied to the embankment on consolidation.

He did not like the Author's use of the expression "time of concentration" on p. 73, *ante*. That expression had become associated in the minds of engineers with a specific meaning, namely, the time at which a flood discharge or run-off could be collected at a particular control-point; but it had not quite the same meaning in the Paper, where the Author was dealing with the coefficient of surface discharge.

With regard to drainage as a whole, soil mechanics did not deal with the condition of the soil alone, but with the condition of soil plus water, and the variation of the water-content, either seasonal or accidental, was a factor which influenced the condition at any moment. Mr. Markwick, in dealing with the water-level contours on a certain aerodrome site (*Fig.* 7, p. 69, *ante*), had referred to one place where there had apparently been seasonal flooding. Professor Clements was sure that the water-table had been subject to seasonal rise and fall, and that therefore the soil within that area had similarly been subject to change in state due to the water/soil relationship.

He believed that the subject of soil mechanics would be of particular interest to the younger generation of engineers, and he considered that it should be brought into the curriculum during their early training; he knew that was being done at one university, at least.

**Mr. A. J. Lyddon** said that the advantage of soil surveys as a preliminary to or a corollary of ordinary surveys was undoubted, but what was particularly needed was some additional knowledge as to what could be done to certain soils in the way of stabilization—in other words, a Paper similar to the lecture delivered by Dr. L. Casagrande to the Institution of Highway Engineers[1], when, in reply to the question: "What do you do with clay in your circumstances?" the Author's answer was: "We introduce sand."

What information could be obtained in regard to the stabilization of soils which were admittedly unstable for certain purposes, namely, aerodromes and runway construction? During the past year Mr. Lyddon had carried out some runway construction, and that had introduced the subject to his mind rather forcibly. With some soils, such as sand, certain possibilities had been opened up; but other soils did not admit of easy stabilization, and a wide field existed, not only for research but also for exploration generally. A good deal of experience had been gained in America; but the conditions in Great Britain differed considerably from those in the United States, and in some respects it was difficult to obtain from the American results much information on the type of soil stabilization to which he referred.

Mr. Markwick had suggested that in the future soil surveys should be regarded not as a matter of research, but as a part of the routine survey. Mr. Lyddon subscribed entirely to that view, but he did not altogether agree with some of Mr. Markwick's remarks on drainage. One still came back to that unfortunate material, clay, which presented many problems in regard to its use as a foundation. That applied not only to roads but still more forcibly perhaps to runway construction.

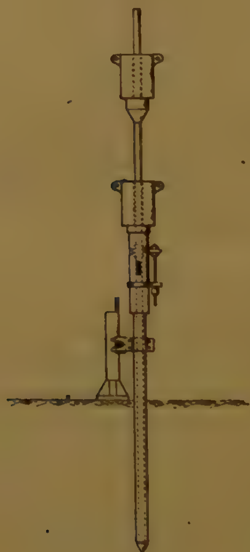
**Mr. G. B. R. Pimm** observed that he wished to express his gratitude to Mr. Cooling for withdrawing the reference to his Paper, made in the

[1] "Soil Mechanics in Road Construction," Bull. Instn. Highway Engrs., No. 11, May 1938.

advance proof. The opinion appeared to be fairly general that laboratory methods, to be of real value, must be supplemented by information obtained in situ as to the behaviour of the ground. Mr. Pimm would go farther and say that, whatever laboratory tests were considered necessary, they must be determined by prior knowledge of the behaviour of the ground as ascertained by in situ tests. Mr. Cooling had conceded that such information might be of value, but, in failing to do justice to the available methods of obtaining it, he had perhaps also fallen short in his estimate of the value of the information when obtained.

*Fig. 1* illustrated a method of sounding which Mr. Pimm had described

*Fig. 1.*



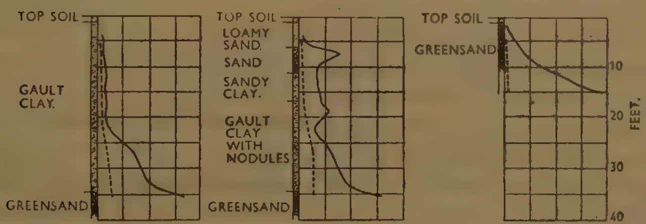
in 1938[1]. The apparatus consisted of a tube with a mandrel running through it and terminating in a point, which was shouldered out to the same diameter as the tube, so that the whole apparatus could be driven as a pile by means of the lower hammer, or, alternatively, the mandrel could be driven alone by means of the upper hammer. An incidental advantage was that the presence and depth of a fissure were immediately revealed by the fall of the mandrel. Two instruments, one on the right and the other on the left, provided alternative checks upon the total bearing resistance.

[1] "Recent Developments in Deep Ground Testing", *Structural Engineer*, vol. 16, p. 210 (July 1938).

The same result should be obtained from each, and actually that was the case, with the qualification that one recorded the set and the compression, whilst the other gave a direct reading of the resistance, and so the difference between them was simply the coefficient which was introduced into the formula used. Then there was a loading test, either for the whole apparatus or for the mandrel alone, and finally a check on the frictional resistance was applied by registering the pull necessary to extract the tube by means of a statimeter.

*Fig.* 2 showed the kind of information obtained: that on the left was obtained from borings, which were not an essential part of the method: the frictional resistance and the toe resistance were also shown. The tests were made on one bridge site, only 15 feet apart, and each was typical of a number of tests. With three groups of tests of that kind a preliminary picture of the ground conditions was obtained, which, he thought, was of

*Fig. 2.*




considerable value in indicating the programme of soil mechanics tests to be followed. A great saving of time was effected by such a preliminary picture, which could be studied at leisure to enable one to decide where to have the samples taken for tests in the laboratory.

**Dr. W. L. Lowe-Brown** observed that many experienced engineers regarded soil mechanics with considerable scepticism, but he felt that Mr. Cooling's Paper had demonstrated that the methods were sound and, when judiciously applied, could be of the greatest assistance. That was his own experience, based upon personal connexion with the first example given in the Paper. He only became associated with that work after the trouble had occurred, but he knew that everyone concerned was very pleased with the businesslike way in which the Building Research Station had attacked the problem and with their assistance when various schemes for overcoming the trouble were being considered. The building had been in continual use since the remedial measures were completed, more than 3 months ago, and the result was considered eminently satisfactory.

The Author's outstanding achievement was that he had covered a difficult subject without obtruding the mathematical machinery which it was necessary to employ in order to secure the results. Many

experienced engineers distrusted the parade of mathematical gymnastics which bulked very largely in some of the writings of its exponents.

Another factor which perhaps had impeded the more general use of soil mechanics by British engineers was the torrent of articles that had appeared on the subject, owing to the rapid advances which had been made by the very large number of enthusiasts who had been working at it. The very bulk of the printed matter (his own files contained eighty articles) in so many different publications and languages had been far beyond the capacity of the ordinary engineer to absorb, and he hoped that the Building Research Station would collect into one volume the results of all the valuable work that had been done by the Station—so that those results might be available in an easily accessible form. If that could be done it would do much to make soil mechanics methods more generally used in Great Britain.

He considered that the Building Research Station should be consulted in the early stages of every important work where any question arose about the ground that was to be built upon.

**Mr. Guthlac Wilson** considered that Mr. Cooling's Paper should do much to stimulate interest in, and more frequent use of the art and science of soil mechanics at the design stage.

The Author had dealt fairly comprehensively with cohesive soils, but cohesionless materials were dealt with less thoroughly. Some reference might have been made to the cases in which it was necessary to determine whether the naturally occurring density of strata of sand below a structure was above or below the critical. The importance of that had been shown by Professor Casagrande [1] and Mr. J. D. Watson [2]. The taking of "undisturbed" samples of cohesionless material presented some difficulty, but it had been overcome by the use of the freezing process [3]. Reference might also have been made to the determination of the coefficient of permeability of sandy strata in situ by the device of pumping water into boreholes and observing the changes produced in the phreatic surface [4].

With regard to the method of sounding by means of a rod enclosed in a pipe, it would be interesting to know whether attempts had been made to correlate the results of such soundings with the index properties of cohesive strata passed through.

A question arose from an examination of *Fig. 4*, p. 47, *ante*. Mr. Cooling had observed correctly that "the nearer the natural water-content is to

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[1] Report on Critical Density. Appendix B of the Report on "Compaction Tests and Critical Density Investigation of Cohesionless Materials for Franklin Falls Dam." U.S. Engineer Office, Corps of Engineers, U.S. Army, Boston.

[2] Report on Investigations of Critical Density of Sand from Franklin Falls, N.H. *Ibid.*

[3] T. A. Middlebrooks. "Fort Peck Slide." Proc. Amer. Soc. Civ. Engrs., vol. 66, p. 1729 (Dec. 1940).

[4] H. Weber. "*Die Reichweite von Grundwasserschwankungen mittels Rohrbrunnen*," Berlin, 1928.

the liquid limit the softer is the soil." In fact, if the natural water-content exceeded the liquid limit the soil was, for practical purposes, liquid. According to *Fig. 4*, that condition occurred in the sandstone stratum at the bottom. How could that be? The index properties, the plastic and liquid limits, had no meaning when applied to materials such as sand and sandstone. The strata "sand and shells" and "brown sand" shown in *Fig. 4* might have contained sufficient clay to make them more or less plastic.

Triaxial compression tests were rapidly superseding the box shear test in the United States, as it had been found that the results of the latter were largely dependent upon the size of the box.

The portable apparatus for compression tests described in the Paper was paralleled by an even more compact piece of apparatus devised by Dr. M. J. Hvorslev, which could be carried in an attaché case and which tested samples of the size of a thumbnail. Dr. Hvorslev had used that apparatus before 1938, and had correlated the results with tests on specimens of normal size.

**Mr. H. J. B. Harding** observed that there had been a danger of soil mechanics falling into disrepute in some circles as being too theoretical. Certainly some Papers of great brilliance had been published, containing pages of calculus, but they had been described as "chamber music"; they were for cultured tastes and not for everyone. Another side of the subject had now been presented. Mr. Cooling was one of the few English writers whose work on soil mechanics was published in the United States of America. His Paper was very practical, and there was not a differential equation in it.

Before engineers tried to follow the Authors in the higher flights of soil mechanics, it was very desirable, now that the value and scope of the work was so evident, that they should re-examine themselves and make certain that they had a simple, sound geological background and a more lively and vivid sense of the variety of sediments and their condition of deposit than was noticeable at present. The fundamentals of the soil had to be understood before the science of soil mechanics could be built on a proper foundation. Engineers should first realize the existence and nature of their problems, and then they could go to Mr. Cooling and other experts for the solution of those problems. He ventured to dissent from Professor Clements' suggestion of early specialization in soil mechanics, and he agreed with the opposition to early specialization which the President had expressed in his Address[1]. It was far better for a student to spend his time at college in obtaining a sound knowledge of geology, together with some practical experience; he could attempt the higher flights later.

For several years Mr. Harding had been brought into contact with many people who were examining problems connected with the soil and

[1] Journal Inst. C.E., vol. 17 (1941–42), p. 1 (Nov. 1941).

site exploration, from leading members of the profession down to small municipal men and also what geologists would call some useful cross-sections exposing architects and builders. Therefore, whilst his remarks might be a little controversial, they were based upon experience.

He considered that the technical training of engineers was still unbalanced. Many were masters of design in steel and concrete, but had had no geological training; consequently they did not appreciate the complexity and the constantly changing conditions of the soil over long periods of time during which the formation of unconsolidated sediments took place, and, instead of approaching the problem with the proper humility due to Nature, they were wont to dictate to the ground how it should behave, as they did to their steel and concrete material. Certainly a course of geology did not make a man into a geologist, but it lifted the scales from his eyes and gave him more ability to appreciate and respect the vagaries of Nature, which were well shown in Mr. Markwick's *Fig. 3* (p. 67, *ante*).

When the elder Brunel was building his amazing Thames tunnel and was held up by a simultaneous collapse of the tunnel and of his funds, he received no fewer than five hundred suggestions for overcoming his difficulties. None of them was of any use, and he complained bitterly in his Journal that in every case " they made the ground to suit the plan and not the plan to suit the ground." That was 120 years ago, and in spite of the technical development which had taken place, human nature remained unchanged. In the steady stream of designs which had to be tendered for innumerable cases occurred in which the plan bore no relation to the ground. Brunel's words: " Make the plan to suit the ground " should be in every drawing office. It was as wrong to design without regard to the construction as it was to construct without any proper design.

One cause of trouble in site exploration was that borings were not big enough, deep enough, or frequent enough. That was not the fault of the boring contractors, who were very competent and helpful, but was due to the system under which they were compelled to work. Competitive prices were insisted upon for this sometimes vital work, and great was the indignation if their price was more than a few shillings per foot. Therefore all the boring contractor could afford to do was to put an intelligent labourer in charge of such cut-price and intermittent work. Yet engineers accepted the reports and were indignant if those turned out to be wrong. In fact, the approach to the problem was truly British; it was a mixture of wishful thinking and reckless economy. On any work of importance competitive boring should be prohibited: A proper and sufficient sum should be allowed (if he were asked what was a sufficient sum he would say " Think of a number and double it ") and time and trouble taken over the borings, which should be supervised by an engineer with both a practical and a geological background. Proper steps should be taken to study the ground-water levels and their variations, and filter-tubes should be left in

the borings when the boring-tube was taken out, so that the variations could be studied. He had been privileged to see a sheet of borehole records made under the supervision of one of Mr. Cooling's colleagues, which were a model of what borehole records should be, and he suggested that a similar sheet should be reproduced in the Journal.

There was a first-class Geological Survey in Great Britain, but its existence was little known. He considered that its scope should be widened and that borehole results should be reported to it. Further, financial support should be accorded to enable the Geological Survey to provide young geologists, with a knowledge of their particular neighbourhoods, to supervise the borings, and thus to benefit both the Survey and the community. He believed that in the State of New York all site explorations had to be carried out by the State, and that seemed a very sensible idea. Many people were unaware of the 6-inch Geological Survey maps of the London area, which contained a wealth of information for those who could read them.

Because boreholes were made by a few specialist firms, very few engineers had had actual personal experience of boring, and many hardly knew a shell from an auger. That was one reason for the lack of appreciation of boring problems. It would be no bad thing if engineering colleges equipped themselves with a 6-inch hand boring gear. Students would learn a great deal by putting down a 50-foot bore in some suitably varied strata and would obtain much healthy exercise.

The absence of any geological sense and knowledge on the part of clients, promoters, and committees responsible for commissioning work prevented proper expenditure on site exploration, and their opposition had to be overcome by the engineer. From his own observation it had been brought home to him very forcibly that the small man, however willing he might be to carry out proper site exploration, was in need of protection and assistance to overcome the opposition of his clients or of committees of very hard-headed business men to this expenditure, in a way that was not the case with the big engineer. That support could and should be given by The Institution, and he suggested that leading members should from time to time make definite statements or pontifical utterances upon the need for proper investigation, so that the less influential engineer could quote them and so obtain the support of which he was in need.

Another man in need of support was the engineer working with, and far too often under, an architect. The architect mind started at ground-level. The architect could design and build the most beautiful structures, but anything below ground was psychologically abhorrent to him. He wanted to get on with his porticos and his pilasters, his parapets and his plumbing. Any deep foundation work merely added to the cost and delay, whilst the work done was not visible, so that he was not so sensitive to the need for site investigation. Moreover, when an engineer was called in by an architect to deal with some question of a leak in a basement or

some other defect in an existing structure, it was often very difficult to find any record of the strata upon which the structure was built.

**Mr. R. V. Allin** observed that the insistence on obtaining undisturbed samples was doubtless essential, but it seemed to require some qualification, because it tended to obscure the fact that the ground under deep open foundations in clay was usually disturbed *after* the preliminary sample had been taken. The chief causes of disturbance were swelling and vibration from pile-driving, both of which were exaggerated by contact with water. An undisturbed sample taken before excavation operations had commenced would not be characteristic of the condition of the soil under load.

That aspect of the subject had already been dealt with by Messrs. Cooling and Skempton [1], who had stated that "the compressibility of clay is more than doubled if the clay is allowed to swell and soften in contact with water." Their tests on samples indicated that swelling of highly consolidated clays took place when the original overburden of those clays was reduced: that would occur in the case of excavation. They also stated that London clay, with its fissured structure, was likely to be particularly sensitive to such disturbance as pile-driving. The opening up of the fissures, and the consequent softening of the soil in contact with water, tended to alter the properties to an important extent. Some or all of those conditions must frequently prevail in deep open foundations in clay, however carefully the work was carried out. Even if it were possible to keep the bottom dry, which was often very difficult, it would be brought into contact eventually with the wet concrete of the foundation slab, and then all the elements required for swelling of the clay would be present. In some deep foundations of that description with which Mr. Allin had been recently connected it had been proved by site observations that appreciable swelling commenced at foundation-level when the excavation had reached only about 6 feet above that level. That swelling continued until the foundation had been poured. It followed that the clay under the foundation must have been in a swollen condition for at least that depth when the slab was poured.

In order to investigate the disturbance caused by pile-driving on an open foundation on highly-fissured London clay, he had recently carried out some very rough laboratory experiments.

With a Langtry Bell shearing-machine a comparison was made between the behaviour of clay samples under ordinary test conditions (in about 5 minutes and with steady load) and the behaviour of clay samples sheared in 48 hours, during which the table was slightly vibrated at intervals to simulate adjacent pile-driving. The test was intended to give an idea of what would happen if fissured clay was shaken up with pile-driving adjacent

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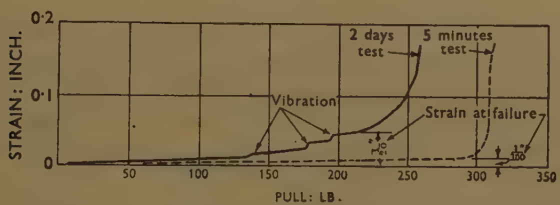
[1] L. F. Cooling and A. W. Skempton, "A Laboratory Study of London Clay." Journal Inst. C.E., vol. 17 (1941–42), p. 251 (Jan. 1942).

to a deep open foundation. In both cases the samples were kept under a normal pressure equal to the overburden load of the clay at foundation-level. *Fig. 3* illustrated the results in the two cases. The heavy line showed the result of the test which was intended to simulate the conditions of vibration from close pile-driving: it lasted 48 hours, during which intermittently a very slight vibration—much less than that effected by pile-driving—was applied to the table holding the machine. The other test was a perfectly normal one, conducted for 5 minutes with steady load. The results were as follows. The vibrations started a premature plastic flow, which finally reached its ultimate, and the sample collapsed at 75 per cent. of the value of the steadily sheared specimen; the plastic flow of the specimen which had undergone a slight vibration was $\frac{1}{20}$ inch, whereas the plastic flow of the steadily sheared specimen was $\frac{1}{100}$ inch.

No finality could be claimed for those results, because the experiments were rather rough, but there seemed to be no doubt that vibration, by inducing strains in the clay—especially fissured clay—weakened its struc-

*Fig. 3.*




ture and reduced its resistance to shear. The results were of particular interest having regard to the close relationship shown by Mr. Cooling to exist between shear and settlement. It appeared that all the characteristics of clay which controlled its stability under load might in actual practice be adversely changed for some distance below the foundation-level during constructional operations, and that therefore undisturbed samples taken within that zone before those operations had been commenced would give unduly optimistic results, which would require correction in the light of site observations.

**Mr. G. T. Bennett** said that one of the chief uses of soil testing on the site should be to determine, in the case of roads and aerodrome runways, what could be done by stabilizing unsatisfactory soils as an alternative to the provision of a satisfactory foundation by removal of the soil to a certain depth and its replacement by imported material. There was also the possibility, with more suitable soils, of providing both foundation and running surface by stabilization. In view of the need for economy in the use of imported material during the war period, because it meant economy in time, that was perhaps the most important question on which

guidance was sought at present, and the Papers were chiefly valuable in so far as they helped to give such guidance. The engineers who designed the German *Autobahnen* were meticulous in testing their soils, but somewhat vague in their descriptions of the bearing of the tests upon their practical decisions.

The aim should be to devise tests upon which the practical decisions would be positively dependent.

**Dr. E. B. Bailey** observed that any inquiry that came to the Geological Survey would be answered free of charge and the best available information with regard to the nature of sites would be given. That would, of course, save much work and expense in connexion with preliminary exploration. The Geological Survey did not possess the detailed information necessary to answer all the inquiries that might be made, but it had very much more information than appeared in any of its publications, and it was willing to supply that information to anyone who needed it. In the case of any work that bore upon the war effort, he was prepared to send out a man specially for two or three days, on payment of travelling expenses and field allowance.

*** **Mr. F. M. G. Du-Plat-Taylor** observed that the surface drainage of aerodrome runways was important from the aspect of non-interference with operations and also from that of camouflage. It was well known that even a thin film of water was visible in moonlight, and therefore it was important that the surface should be kept dry. With a rigid type surfacing of concrete that could be ensured only by a sufficient camber or cross-fall to discharge the rainfall to side drains.

A honeycomb type of asphaltic surfacing used as a carpet to a normal concrete base would absorb rainfall up to its capacity, which depended upon its thickness, and transmit it laterally to side drains; but in order to meet the requirements of the heaviest rainfall on a runway 150 feet wide a considerable thickness was required, as the rate of lateral transfer was necessarily low. On the other hand, asphaltic surfacing of that type was very efficient when used as a flexible surfacing laid direct upon pervious soils, and in combination with under-drains.

Experiments had been made with pervious concretes composed of aggregates ranging from 1½-inch to ¾-inch gauge with a small sand-content. Those concretes were perfectly pervious and had a reasonable compressive strength. They were, however, deficient in tensile strength, owing to the area of contact between units of the aggregate being so small, and would be likely to fail under load if required to act as a rigid surfacing.

In the civil aerodrome at Singapore [1] perforated precast concrete slabs were used in the tarmac area to transmit rainfall to the drains beneath, and that appeared to be the best method of combining adequate strength with free transference of rainfall to the drainage system. It was, however,

*** This and the following contributions were submitted in writing.

[1] Journal Inst. C.E., vol. 12 (1938–39), p. 69 (June 1939).

open to the objection that the perforations might soon become clogged by dirt and so cease to function. It would be interesting to know what had been the experience at Singapore.

In Mr. Du-Plat-Taylor's view the ideal rigid surfacing should consist of perforated concrete covered with a layer of pervious asphalt. The perforation of concrete laid in situ appeared, at first sight, to present serious difficulties; but he thought that by employing vibration applied to the bars used mechanically for perforation those difficulties could be overcome without serious expense.

**Mr. R. Glossop** observed that as soil mechanics was a new subject much research was in progress, and many of the Papers published were intended for the specialist. They were often mathematical in form and the practical application of their conclusions was not always obvious; therefore many engineers regarded the subject as highly theoretical and inapplicable to everyday foundation problems. That was a mistake, and the importance of Mr. Cooling's Paper lay in his emphasis of the value of certain simple soil tests, and of their interpretation by methods involving nothing more difficult than the elementary theorems of statics. Formerly the measurement of shear strength by compression tests required cumbersome laboratory apparatus, but the apparatus illustrated in *Figs.* 5, p. 49, *ante*, could be set up beside a borehole and values of the shear strength of the soil, sufficiently accurate for most purposes, could be obtained as boring proceeded. The examples described formed a convincing proof of the value of that technique, of the accuracy of its results, and of its wide field of application. Indeed the fact that four out of five of the examples described were "post-mortem" examinations after the failure or partial failure of a structure, showed how much scope there was for that essentially practical branch of the science of soil mechanics.

That certainly justified Mr. Cooling's approach to the subject of site exploration, but as a result of it he has confined himself, in his examples, to cases involving one only of the two main soil groups, the cohesive soils. Those contained a high proportion of clay and owing to their low permeability reacted slowly to changes in their state of stress. As a rule they were easy to excavate, and to support during excavation, but settlements might continue for a long time after completion of the structure.

Examination of soil conditions on a site, apart from questions of stability, was also of value in determining the best method of construction, which, in turn, should influence the design of the structure. That aspect of site exploration was chiefly concerned with the properties of the non-cohesive soils—gravels, sands, and silt, which were characterized by a high coefficient of permeability, wide range of particle-size, and absence of plasticity. In contrast to the cohesive soils, they usually formed a stable and reliable foundation. It was during, not after, the construction period that troubles arose, for the high permeability permitted of a heavy flow of water through the soils, whilst their lack of cohesion resulted in sand

being carried to the excavation by the inflowing water, so that settlement of the ground adjacent to it might follow.

Numerous precautionary methods were available for carrying out excavation in such soils; the most important were sheet-piling, compressed air, open caissons and cylinders, freezing, and injection processes, the latter including the injection of cement, clay, or bentonite grouts, bituminous emulsions, and finally the process of chemical consolidation based upon the injection of soluble silicates. Although many factors influenced the choice of method in any case, the properties of the ground were always of decisive importance, for the design and method of construction had to be adapted to the ground, since the ground would not accommodate itself to the method. When deep excavation had to be carried out in non-cohesive soils, carefully supervised borings followed by mechanical analyses and permeability tests on the samples should be made, so that a logical combination of design and construction could be formulated.

Methods of boring and sampling varied with differing soil types. To take undisturbed samples of a sand was difficult, although it could be done; fortunately it was rarely necessary, and reliable samples could be taken with a standard boring tackle. The casing should be driven well ahead of the bottom of the hole, and the ground, as removed with the sand pump, emptied into a tub from which the water could be decanted after the fine material had settled. Mechanical analyses of such samples were very instructive, and as they could be so easily carried out it was unfortunate that they were not more widely used in Great Britain. All too often accounts of difficult excavation described the ground in vague and general terms. A semi-logarithmic plot from a sizing analysis would yield precise information, in a form easily comparable with that from other cases, as was shown in *Fig. 4.* Curve No. 1 represented gravel from the Thames flood plain terrace at Millbank, the familiar Thames ballast, and the composite curve was characteristic of such material; curve No. 2 was of a beach sand from Hayle, Cornwall; an attempt to treat that material with cement injection failed, as might have been expected, since the material was too fine to be treated even by chemical injections; curve No. 3 was of well-known Cretaceous sand from Leighton Buzzard, which could be easily consolidated by chemical injections; curve No. 4 was of a river sand from a valley in the Keuper marls of Staffordshire; that fine sand was successfully drained by ground-water lowering by means of well-points. It was evident that much could be learnt by merely comparing the curve for a soil with those of materials whose response to various forms of treatment was known, such as those illustrated.

Mr. Glossop's experience of the unconfined compression test agreed with that of Mr. Cooling, namely that it was not well suited to the examination of stiff fissured clay, such as London clay. The following rapid procedure yielded useful information with such soils. Four or five samples

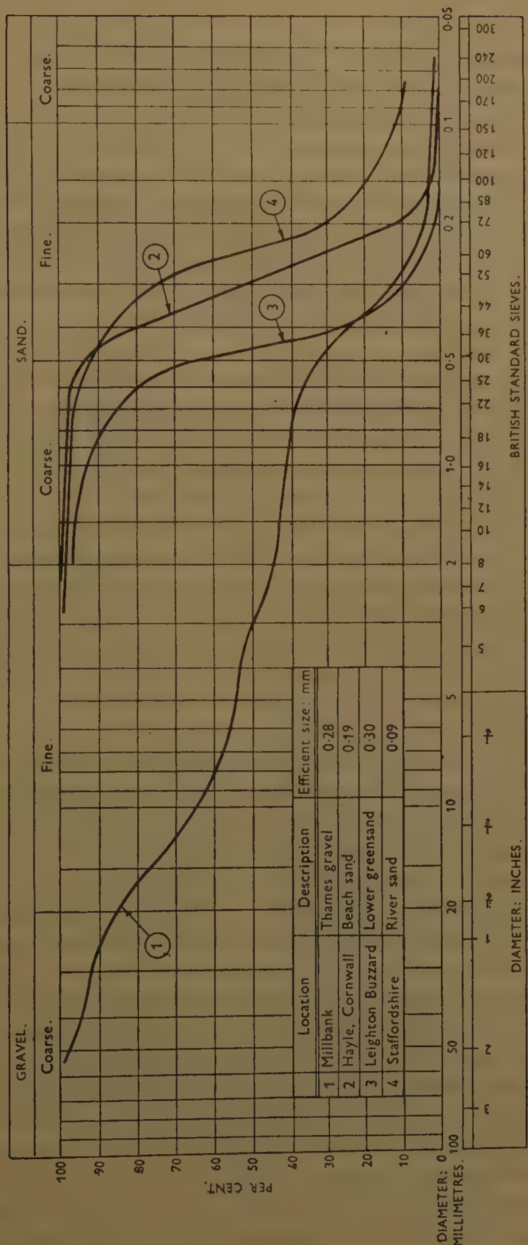

GRAVEL.
SAND.
Coarse.
Fine.
Coarse.
Fine.
Coarse.
PER CENT.
DIAMETER: MILLIMETRES.
DIAMETER: INCHES.
BRITISH STANDARD SIEVES.
Location
Description
Efficient size: mm
1 Millbank Thames gravel 0·28
2 Hayle, Cornwall Beach sand 0·19
3 Leighton Buzzard Lower greensand 0·30
4 Staffordshire River sand 0·09

*Fig. 4.*

should be taken in a group as close together as possible; the groups might be spaced at about 5-foot intervals of depth, or whenever a change in the soil was observed. Examinations of the type of failure in the test-pieces of each group would lead to the rejection of those in which failure had obviously taken place along a pre-existing plane of weakness.

Boring, sampling, and testing should all be carried out under the immediate supervision of the engineer responsible for the investigation. Satisfactory results could not be expected if samples were taken in a haphazard manner by a foreman, and submitted to routine tests by a laboratory worker unfamiliar with the geological conditions at the site.

**Mr. H. Q. Golder** observed that soil sampling was of such importance in soil mechanics work that a few remarks on some practical points might be of value.

The simple method of site exploration described by Mr. Cooling really was simple, but it could give results of very great value. One point to watch was that when sampling in very soft materials the soil at the bottom of the hole might soften up in the time occupied in withdrawing the rods, replacing the auger by the sampling-tool, and taking the sample. To overcome that difficulty it was necessary to have two sets of rods, so that the sample might be taken immediately the auger was withdrawn and before any appreciable softening had taken place. At the other extreme, in hard clay, if the weight of two men failed to push the sampling-tube into the clay, its compression strength was probably more than 25–30 lb. per square inch, which was usually adequate in problems which could be satisfactorily treated by that method of site exploration.

When boring with well-boring equipment it was usual to employ a specialist firm; but it was well to bear in mind the difference in outlook of the soils engineer and the ordinary well-boring foreman. The latter was usually interested only in boring a hole by the quickest possible means, whilst the soils engineer was not interested in the hole, but in the material through which the hole passed. That difference in outlook was very important, for unless the foreman had that fact impressed upon him and was sufficiently intelligent to realize its importance, the engineer had to be constantly on the job during the boring operations, or poor samples would result. Even with an intelligent foreman it was essential that the engineer should spend considerable time on the job in the early stages of a project of any magnitude, inspecting the material brought up, supervising the sampling, and collecting information about water-levels. When he was satisfied that the foreman was thoroughly conversant with the method of sampling and would carry out his instructions conscientiously, his attendance on the job could be reduced.

Boring should be done dry, and on no account should water be poured down the hole to make boring easier. The levels at which water flowed into the hole should be carefully recorded, together with the level to which the water rose in the hole and the time taken for that rise to occur,

Sampling was an operation which required some care. The sampling-tube should be finished with a smooth surface inside and out and should be kept clean and free from rust and scale. Before use it should be oiled all over. The blow used to drive in the tube should not be too violent. The tube should not go into the soil in $\frac{1}{2}$-inch jerks; $\frac{1}{10}$ inch was more the order of movement required. From that point of view the practice of using the weight of the rods to drive in the tube might not be good in soft material when sampling at considerable depths. Possibly the best system to use for driving in the tube would be to have a sliding monkey working on the bottom rod and driving direct on to the top of the head of the sampling-tube, the monkey being operated from the surface by a rope.

In Appendix I of Mr. Markwick's Paper, the Author had stated that "When friction is present the ultimate bearing capacity of the loaded circular area is about twice that of the loaded strip." That statement was based solely upon the results of theoretical analysis, but tests which Mr. Golder had made to test the point [1] had shown that the statement was untrue, and that a square (or circular) area on a frictional soil would support only the same pressure as a strip of the same width.

The difference shown in *Figs. 13*, p. 83, *ante*, was not the difference between a circle and a strip, but the difference between two different methods of analysis, since although Mr. Markwick had based his analysis upon Terzaghi's method, the assumptions he had made regarding the circumferential stress *Pt* probably invalidated the comparison. It was interesting to note that if the coefficients for Prandtl's formula for a strip footing were plotted in *Fig. 13*, they lay very close to, or above, the Author's value for a circular area.

**Mr. A. W. Skempton** observed that the art of obtaining undisturbed samples of soil was, perhaps, not widely practised in Great Britain. It was, however, widely acknowledged as being a basic requirement in site exploration; and its importance was due to the fact that the properties of a soil could be completely altered by disturbance. A good illustration of that was provided by the soft blue clay shown in *Fig. 6*, p. 52, *ante*, which lost rather more than 75 per cent. of its strength when it was remoulded in the fingers; and any calculations based upon even a partially remoulded sample would clearly be of little practical value. But in a site exploration it was not sufficient merely to obtain good samples. It was also necessary to make observations in the field on all the factors which might influence the constructional operations or the finished structure. Mr. Cooling had mentioned some of those factors on pages 38 to 40, *ante*, and outstanding among them was the observation of ground-water levels.

The significance of ground-water levels was, in many cases, quite obvious. Thus if any excavation had to be carried through alternate layers of sand and clay, it was advantageous to know the head of water

[1] Journal Inst. C.E. vol. 17 (1941–42), p. 161 (Dec. 1941).

which would be encountered in the sand. It might, however, be desirable to know the water-pressure in a sand layer below foundation-level; that point was brought to notice, particularly, in the investigation of example IV, *Fig. 9* (p. 59, *ante*), of a small building which became severely cracked. The cracking was due to the excessive deformations of an underlying layer of soft clay; and the deformations were, in their turn, due to the unbalanced weight of the banks surrounding the building. The remedial measures were very properly carried out by cutting back the banks and thereby reducing the stresses in the soft clay.

Both the remedy and the explanation of the failure were thus quite straightforward. But it was thought that the mode of occurrence of the soft clay was rather curious. The facts relating to the soft clay were therefore assembled and were found to be as follows:—

(1) The soft clay lay on a bed of sand and silty clay, containing artesian water which overflowed in all the borings, including boring B at ground-level.

(2) The soft clay extended in the form of a flat pocket beneath the excavated area; but it did not appear to extend beneath the banks. Thus it was found in borings E and VII, but not in borings B and VI.

(3) There was no significant difference between the type of clay constituting the "soft clay" and the "medium-soft clay" in *Fig. 9*; and it was probable that they were deposited in an ice-dammed lake during the retreat of the glaciers from England.

(4) The building became cracked 6 months after construction.

It might be asserted that any relation between those facts was coincidental; but the following tentative explanation of the occurrence of the soft clay was, at least, not at variance with any of them.

Considering the clay at the position of core B in boring E below the centre of the building: before excavation took place it was about 32 feet below ground-level and was therefore under a total downward pressure of about 4,000 lb. per square foot. But the water in the silty clay, lying just below core B, was under a head of at least 32 feet, since it overflowed in boring B at ground-level. There was, therefore, an upward pressure on core B of at least 32 feet of water, and the net pressure acting on the clay was therefore about 2,000 lb. per square foot. Excavation then took place, and 18 feet of clay was removed. This would approximately halve the total downward pressure, whilst no change would occur in the water-pressure, since the sand lay entirely below foundation-level. It would therefore be seen that the net pressure on core B was reduced to zero and, in fact, there was a slight tendency for the clay to be lifted off the sand since the water-pressure was rather greater than the weight of the clay alone. The result of that reduction in net pressure was that the clay would start softening: and the softening would continue for many months, or even years, gradually spreading upwards and reducing the strength from about 1,000 lb. per square foot to 350 lb. per square foot. The latter strength was con-

siderably lower than the stress set up by the weight of the banks, and deformations would therefore occur, increasing with time, and ultimately being sufficiently large to crack the building. The period of heavy rain mentioned by Mr. Cooling would accelerate the process by temporarily increasing the shear stresses.

If that explanation were correct, the soft clay was a consequence of excavation. It therefore followed that where there had been no excavation there should be no soft clay; and that had been mentioned already as a fact. It also followed—and that was the important point—that if the borings had been made before excavation no soft clay would have been found; but only "medium-soft clay" with a shear strength at least double that of the existing soft clay.

That example therefore demonstrated the need for observing water-levels and for taking into account the changes brought about by constructional operations. In itself the example was not important, since the building was easily repaired: but a similar set of conditions could easily be imagined in the case of a quay wall, where the results would be disastrous unless foreseen and allowed for in design.

**Mr. J. S. Jackson** observed that he had noted with some misgiving that more than one speaker had referred to soil mechanics as a suitable subject for study by young engineers, or even students. They seemed to regard it as a matter that could be left to the next generation. He dissented strongly from that view and regarded the subject as of urgent importance. As Mr. Lyddon had said, there was immediate scope for the application of a knowledge of soil mechanics in connexion with the construction of aerodromes and military roads. Soil stabilization methods were already available and had yielded very promising results, not only in the laboratory, but also in practical field trials. He felt, therefore, that those methods should be thoroughly explored on an extensive scale, so that suitable plant might be chosen and assembled and as much practical experience as possible gained. It was obviously in the national interest that the accumulated knowledge of soil stabilization should be rendered available for practical use as quickly as possible. It was conceivable that successful soil stabilization might have a critical influence upon the nation's military fortunes in its world-wide operations, since it was obvious that the rapid construction of roads and aerodromes from readily available materials was of fundamental importance.

He had no doubt that if the Government could be persuaded to invest £100,000 on research work on soil stabilization a very large dividend would be paid within the course of two or three years.

**Mr. Cooling,** in reply, thanked the members for the way in which they had received his Paper and for the very helpful remarks which had been made in the discussion. He had been particularly gratified by Dr. Lowe-Brown's remarks with regard to the example given in *Fig. 6*, p. 52, *ante*. He was glad to know that the action taken by the Building Research Station in that

case had proved to be satisfactory. News of the performance of structures with which they had been connected was always of interest to those engaged at the Station, and more especially in those cases where the actual behaviour differed from that forecasted, for the research man, like the engineer, learned most of all from his mistakes.

Some speakers had suggested that there was in the minds of many engineers an impression that soil mechanics was a highly theoretical subject. That was definitely a wrong impression and he hoped that his Paper had gone some little way towards correcting it. As a further step he would suggest a reference to the Presidential Address given by Professor Terzaghi in 1936 to the First International Conference on Soil Mechanics [1] in which the progress achieved and the outlook adopted in soil mechanics was dealt with in more authoritative terms than he could hope to give.

Whilst it was true that many soil mechanics publications were of a specialist nature, in which mathematical methods assumed some prominence, he thought that that was a necessary aspect and an inevitable result of the intensive study devoted to the subject. That feature, however, should not obscure the fact that broad progress in the subject as a whole depended upon the closest possible contact with practical problems and the continued study of the behaviour of soils in the field. An essential requirement of such progress was the active co-operation of the practising engineer, a point which was illustrated by the few practical examples quoted in the Paper, the study of each of which owed much to the collaboration of the engineers in charge. The teaching of soil mechanics, which was mentioned by Professor Clements, was also an important aspect. That had been gone into in some detail in the United States, and he thought that the Proceedings of the Purdue Conference on Soil Mechanics (July 1940) would provide valuable information for those interested in that aspect.

The suggestion put forward by Dr. Lowe-Brown relating to the publication of the results of investigations carried out at the Building Research Station would certainly be borne in mind, but there were difficulties in putting that work in hand at present.

Many speakers had quite rightly emphasized the value of a knowledge of the geology of a site as a preliminary to site exploration. He thought, however, that it was necessary to point out that for purposes of design, geological information should be supplemented by quantitative data obtained from soil tests.

The need in Great Britain for a better appreciation of the necessity for, and the value of, adequate site exploration had been dealt with in masterly style by Mr. Harding, and Mr. Cooling wished to express his thanks for a valuable and entertaining contribution.

[1] Proceedings of the First International Congress on Soil Mechanics and Foundation Engineering, vol. iii, p. 13.

He agreed with Mr. Pimm that the results of laboratory tests should always be considered with an adequate background of information obtained by field observations. Such observations could be made during sampling—a point which had been amplified by Mr. Golder. The brief description of Mr. Pimm's method of sounding was interesting, but he thought Mr. Pimm would agree that for some problems the information it gave was strictly limited, and that for most problems the interpretation of the results needed considerable experience and a knowledge of the soil strata obtained either from geological records or from borings. For instance, he did not know how the nature of a soil stratum could be inferred from penetration resistance alone, or how the method could give information relating to ground-water pressures in the various strata, a factor which might represent a very important hazard during construction. In reply to Mr. Guthlac Wilson's question on sounding methods, he could only state that, so far as he knew, no systematic attempt had been made in Great Britain to correlate the results of such soundings with the index properties of cohesive soils.

He agreed with Mr. Wilson that perhaps cohesionless soils had not been treated adequately in the Paper; but it was difficult to include all aspects of the subject when space was limited. On that account he welcomed both Mr. Wilson's and Mr. Glossop's comments, which indicated the troubles most likely to be encountered with soils of that type. It was true that index properties had less meaning when applied to sands or to the material brought up by boring into sandstone. *Fig. 4*, p. 47, *ante*, showed the results of routine tests on samples from a soil profile, but naturally those would be considered in the light of boring records, and the results given for the sandstone samples in *Fig. 4* would be ignored.

He was interested in the details given by Mr. Wilson of Dr. Hvorslev's portable compression apparatus. That apparatus was mentioned in Hvorslev's Paper[1], but no details had been published so far as he knew.

He thought Mr. Allin had made a valuable point in drawing attention to the fact that important changes might take place in the ground as the result of constructional operations such as deep excavations and piling. The example quoted by Mr. Skempton was a further illustration of that point, and the suggested explanation of the formation of the soft clay layer was particularly interesting.

Mr. Cooling thought that measurements of the swelling of clay in deep excavations such as those made by Mr. Allin constituted a valuable contribution to the science. The explanation of the results of the laboratory test described by Mr. Allin was interesting, but the experiment could hardly be considered conclusive. A very slow shear test under small normal loads usually gave a lower strength than a quick shear test, and possibly the increased deformation following vibration might be due to a

[1] M. J. Hvorslev, "The Present Status of the Art of Obtaining Undisturbed Samples of Soils," *loc. cit.*, p. 13.

seismic effect on the weights used to supply the shear load which temporarily increased the shearing force.

**Mr. Markwick**, in reply, said that he had not dealt with the problem of soil stabilization because he had recently presented a Paper on that subject to the Institute of Petroleum[1]. A number of soils could be dealt with by stabilization. Mr. Lyddon had successfully constructed runways at a number of aerodromes by stabilizing the natural sand, and Mr. Markwick had come across a number of sites where other types of soil could have been successfully stabilized, whereby a good deal of effort and expense would probably have been saved.

Professor Clements had observed that a soil survey was a lengthy process. As a matter of fact, about two weeks' work on the site by an engineer and possibly one or two labourers was required for the soil survey for an aerodrome, and the total cost of that survey, including the tests in the laboratory, was about £150. There would probably be 200,000 or 300,000 square yards of surfacing to be done on the aerodrome, costing about £100,000—£150,000, so that the cost of the soil survey would be about 0·1 per cent.; and the value of that expenditure, as an insurance against unsatisfactory foundation conditions not otherwise apparent, was considerable.

The Road Research Laboratory always made use of the drift maps of the Geological Survey before starting on a soil survey, because the information given was a useful indication of the conditions which would be met at the site.

Professor Clements had pointed out that soil was one of the principal constructional materials used by civil engineers. In the Author's view that alone justified Professor Clements' proposal that soil mechanics should be brought into the curriculum of young engineers as a part of their early training. Mr. Harding, however, had dissented from that view, advocating that the civil engineering student should acquire a sound knowledge of geology instead. The Author would be the last to question the necessity for a grounding in geology, but the view which Mr. Harding had put forward suggested that he had failed to appreciate the essential difference between geology and soil mechanics. The former was essentially a descriptive science, but soil mechanics endeavoured to explain the phenomena with which it was concerned in quantitative terms, and was thus closely allied to structural engineering. There was, however, an important difference: unlike mild steel, soil was a variable material, and it was therefore necessary in every case to assess the properties of the soil by means of tests on samples taken from the site. The very basis of "soil mechanics" was the combination of laboratory experiment with applied mechanics, and that had been responsible for the rapid developments in knowledge of the engineering properties of soils. It was interesting to

[1] See reference 3, p. 86, *ante*.

ecall that Mr. Bell[1] had been one of the first—if not the first—to study oundation problems by means of tests on samples taken from the site.

Mr. Jackson had urged that, however desirable as a subject of study for oung engineers, soil mechanics was also of urgent present importance. The Author felt that by their support at the present meeting and at all he previous meetings when soil problems had been discussed, members ad made it clear that they agreed with Mr. Jackson, and were, as Mr. Bennett observed, particularly eager to acquire knowledge upon which ractical decisions could be based. That raised the question of the dis-emination of a knowledge of soil mechanics among engineers. Dr. Lowe-Brown had pointed out that the latest information was frequently contained n numerous technical Papers and articles. It was to assist engineers to over that technical literature with the minimum of effort that the various bstract journals existed. Soil mechanics was covered in three journals, "Road Abstracts," "Building Science Abstracts," and "Aerodrome Abstracts," the titles of which would be familiar to members. Summaries f information in readily usable form were sometimes given in Papers on articular aspects; whilst yearly summaries of research on road problems ad been included for a number of years in the year-book of "Roads and Road Construction." Although a British textbook was not yet available, here were a number of American textbooks, two of which had been already eferred to [2].

There seemed to be general agreement among engineers as to the lesirability of adopting improved methods of investigating soil conditions, nd the Author hoped that more might be done in the future to carry out nvestigations which had been agreed to be desirable. Those ideas were y no means new, and since he had written the Paper the Author had been ery interested to notice in a book on road construction [3], published in 1833 by an Honorary Member of The Institution, an account of practice aid to have been followed by Telford. The following quotation might e of interest:

> "A vertical section should be made, and the nature of the soil or different strata should be shown over which each apparently favourable line passes, to be ascertained by boring; for it is by this means alone that the slopes at which cuttings and embankments will stand can be determined and calculated. . . .
>
> "If bogs or morasses are to be passed over, the depth of the peat should be ascertained by boring; and the general inclination of the country for drainage should be marked."

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[1] See reference (22), p. 87, *ante*.

[2] See references (1) and (2), p. 86, *ante*.

[3] Parnell (*Sir* Henry), *Bart.* A treatise on roads. London, 1833. (Longman, Rees, Orme, Brown, Green and Longman), p. 40.

In reply to the query regarding the propriety of using the term "time of concentration" on p. 73, *ante*, that term had been used in the sense defined by Professor Clements, namely, for the time after commencement of rain at which maximum run-off occurred in the main arterial drains.

The use of porous concrete of the type referred to by Mr. Du-Plat-Taylor was of considerable interest. The Author believed, however, that by attention to the grading of the aggregate it was possible to obtain a satisfactory open-textured concrete surfacing, that did not need to be covered with a bituminous carpet. The Author was not quite happy, however, about Mr. Du-Plat-Taylor's proposal to lead the run-off directly into the soil because of the danger of softening it, although there were, no doubt, cases where that form of construction could be adopted with safety.

Mr. Golder had asserted that his tests had shown that on a frictional soil the bearing capacity of a circular area was the same as that of a loaded strip of the same width irrespective of its length; but his Paper [1] showed that those tests had been carried out on square and rectangular footings and not on circular areas. Mr. Golder's evidence was, therefore, inconclusive, especially as Terzaghi [2] had quoted two sets of experimental data on the bearing capacity of circular areas on sand which supported his formula. Hence the conclusion given in the Paper.

The Author was glad that Professor Clements had referred to the application of controlled methods to embankment construction and had agreed that that application of soil mechanics was not a counsel of perfection but a method of considerable practical value. It was, perhaps, fortunate for contractors that although the Resident Engineer now had a method of assessing the degree of compaction which reduced the scope for argument, modern constructional methods based upon scrapers and tractors were capable of meeting quite stringent requirements without undue cost and as a part of the ordinary construction routine. Those methods of control had been welcomed in America, and the Author did not think that contractors had anything to fear from them.

In thanking members for their kind reception of his Paper, he wished to express his regret, in view of the wide interest expressed, that it had not been possible to deal with soil stabilization. He had already indicated the primary reason, and he agreed that it was a subject of national importance.

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The following corrections should be made to the Paper as printed in the Journal:—

Page 70, Conclusion (3), line 3. *For* "(wheel-load$_{\frac{1}{3}}$)" *read* "(wheel-load$^{\frac{1}{3}}$)."

Page 82, Equation (9). Insert = sign between first two terms.

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[1] *Loc. cit.*, p. 173, *ante*.

[2] See reference (23), p. 87, *ante*.

## ORDINARY MEETING.

10 March 1942.

PROFESSOR CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S., President, in the Chair.

The President referred to the death of Sir Robert Elliott-Cooper, Past-President, and it was accordingly resolved :—

That the President and Council and the members present at this Ordinary Meeting record the deep regret with which they have learned of the death of Sir Robert Elliott-Cooper, who was elected a Member of the Council in 1900, President in November 1912, and an Honorary Member in February 1938; and that an expression of sincere sympathy be conveyed to the members of his family.

The Council reported that they had recently transferred to the class of

*Members.*

George Boex, B.Sc. (Eng.) (*Lond.*).
Percy St. George Kirke, M.A. (*Cantab.*).
Ernest Proctor, B.Sc. (Eng.) (*Lond.*).
Bessel Rosen, B.Sc. (Eng.) (*Lond.*).
Santhebachahalli Nanjappa Srikantia, B.E. (*Mysore*).
Harold Taylor, M.C.

and had admitted as

*Students.*

Richard John Ash.
Geoffrey Ernest Barltrop.
Donald Beard.
David Bramwell.
Thomas Frederick Brown.
Gareth Ernest Brownjohn.
Thomas Brydon.
Geoffrey Butterworth.
Geoffrey Chadwick.
Neville Thomas Cole, B.A. (*Cantab.*).
Walter Alexander Condy.
Edward Bohun Evans.
David Fisher.
Peter Ingleby Flint.
Dugald Don Fraser, B.Sc. (*St. Andrews*).
Alfred David Wigram Greene.
David Hayon, B.Sc. (Eng.) (*Lond.*).
Twylon Isaac.
John Kenneth Johnson.
Francis Cecil Kyle.
David Chaim Linekar.
Adi Jal Master.
Ian Thomas Munro.
William Joseph Robert Nowson.
Edward Arthur Peat.
Sidney Pepper.
James Priestley.
Cecil Percy Dodd Pywell.
William Robert Rangeley.
George Douglas Renton.
Francis Rodgett.
Geoffrey Thomas George Scott.
Ronald Alexander George Simmons.
Alexander Harold Steele.
Zawen Wahan Tajirian.
James Leslie Webster.
Canapathipillai Wijayanathan.
John Eric Williams.

The Scrutineers reported that the following had been duly elected as

*Member.*

HARRY WATSON SMITH.

*Associate Members.*

NORBURY ANDERSON BENNETT, B.Sc. (Eng.) (*Lond.*).
EDMUND COLLINS, Stud. Inst. C.E.
JACK DUERDEN.
WILLIAM SEYMOUR HARRIS, Stud. Inst. C.E.
DONALD MURRIE HUTTON, Stud. Inst. C.E.
JOSEPH NOEL KENDALL.
IVAN GEOFFREY MOORE, B.Sc., Ph.D. (*Leeds*), Stud. Inst. C.E.
EWART RENTON SHACKLETON, Stud. Inst. C.E.
GEORGE MAUGHAN THOMPSON, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
ENOCH WHARMBY, B.Sc.Tech. (*Manchester*), Stud. Inst. C.E.
OWEN TUDOR WILLIAMS, B.A. (*Cantab.*), Stud. Inst. C.E.
RICHARD GEORGE BROOKS WORDSWORTH, Stud. Inst. C.E.

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

Paper No. 5310.

# "The Surface Finishing of Concrete Structures." † *

By Norman Davey, B.Sc.(Eng.), Ph.D., M. Inst. C.E.

TABLE OF CONTENTS.



## Introduction.

N his Presidential Address in November 1941 [1], Professor C. E. Inglis eferred (p. 9) to "the plausible but pernicious doctrine that if a structure properly proportioned for the duties it has to perform it must be auto-atically pleasing to the eye. That doctrine is one of those half-truths hich can be very dangerous." "Students," he said, "are taught to esign structures which are reliable and economical, but it is very unlikely at they are given the faintest indication that in beauty of form and har-ony with surroundings there are other problems to be solved of almost ual importance."

Particularly would this seem to be the case in the design and finish concrete structures, and there is considerable justification for the view pressed recently by Dr. David Anderson, in the discussion on the Paper



* Correspondence on this Paper can be received until the 15th July, 1942, and l be published in the Institution Journal for October, 1942.—Sec. Inst. C.E.

[1] Journal Inst. C.E., vol. 17 (Session 1941–42), p. 1 (Nov. 1941).

on "Aesthetics of Engineering Structures [1]," read by Dr. Oscar Faber before The Institution in 1941, that ". . . engineers as a whole had failed to produce a satisfactory finish to their concrete structures. Some finishes were deplorable from the start, but even others which were more pleasing to begin with suffered very badly from weather, and at the end of, say, 5 to 10 years were very disappointing from the aesthetic point of view." The most satisfactory structures (using the term "satisfactory" in its widest sense) erected in concrete have been those in which the engineer, the architect, and the contractors have co-operated wholeheartedly, with a view to producing a structure not only efficient in use but also pleasing in appearance. Such co-operation is of almost overriding importance.

Having determined the minimum sections required for structural purposes, the engineer should then consider what additional covering to reinforcement is necessary in view of the surface treatment he proposes to adopt. He should consider very carefully where the contractor is likely to make construction joints. He should then indicate at elevations the exact position of these joints throughout, and specify very closely the surface treatment to be employed. This construction-joint drawing should form part of the contract, being either ratified or amended by the contractor before the tender is accepted. Similarly, the actual details regarding the shuttering and formwork and the method of finishing the concrete should be decided upon before construction is started. The methods available for finishing the surfaces of concrete structures are many and varied, and it is the purpose of this Paper to describe these methods, and to draw attention to some of the precautions that should be taken in applying them.

In the present emergency, when economy in the use of materials and labour and speed of construction are such important factors, it is realized that it may not be possible to put into effect some of the suggestions made. Nevertheless careful design of formwork, by simplification, the elimination of all elaborations, and the adoption of standardized sizes, so essential to the production of good concrete surfaces, also results in marked economy of material and labour.

In whatever circumstances the concrete structure is being erected, whether in time of war or peace, there is no reason why the elementary rules for good concreting should be broken. Speed of construction is no excuse for designing, placing, and finishing concrete in a slipshod manner.

## Experimental Investigation and Survey of Structures.

During the past few years a study of the subject has been made by the Building Research Station in collaboration with the Cement and Concrete Association. The investigation has been divided into two main sections:

[1] Journal Inst. C.E., vol. 16 (Session 1940–41), p. 141 (April 1941).

irstly, a preliminary study, made a few years before the outbreak of war, f concrete structures erected on the Continent of Europe [1], in France, ermany, Switzerland, Austria, and Czechoslovakia, and secondly, an xamination of variously-treated concrete slabs, exposed to the weather in ondon and in two industrial towns in the North of England, and the arrying out of various other tests at the Building Research Station. An xamination has also been made of many buildings erected in Great ritain.

It is not possible within the scope of this Paper to record all the observaions, but an attempt will be made to summarize as briefly as possible the ain conclusions drawn from the work, and to indicate how various nishes can best be obtained and how they may be expected to behave in ractice. The purpose of the Paper is not to suggest which finish should e used in any particular set of circumstances, but rather to indicate the ariety of treatments that can be secured by the proper use of concrete—he most adaptable, yet probably the most abused of our constructional aterials.

In preparing specimens for exposure to natural weathering a standard ize of slab, 2 feet by 1 foot by 2 inches thick, has been adopted. Such a lab gives a reasonable surface-area on which to work and to make observaions, whilst at the same time it can be easily handled. Large numbers f such slabs have been exposed for more than 3 years, and such factors as he effect of richness of mix, variations in the water/cement ratio and in he grading of the fine aggregate, the type of aggregate, and the behaviour f variously-treated surfaces have been examined.

As being typical of the observations, reference will be made to one eries of tests in which all the slabs were of 1 : 2 : 4 concrete, proportioned y weight, but the aggregates were varied, Portland stone, York stone, Velsh granite, and white marble being used. The water-content was djusted with each type of aggregate to produce concrete of the same orkability throughout. The slabs were cast vertically in steel-lined oulds and were compacted by vibration. Four types of surface finish ere examined, namely:

(a) Smooth untreated surface direct from the steel forms.
(b) Scrubbed on de-moulding 24 hours after pouring.
(c) Bush hammered when 7 days old.
(d) Ground when 7 days old.

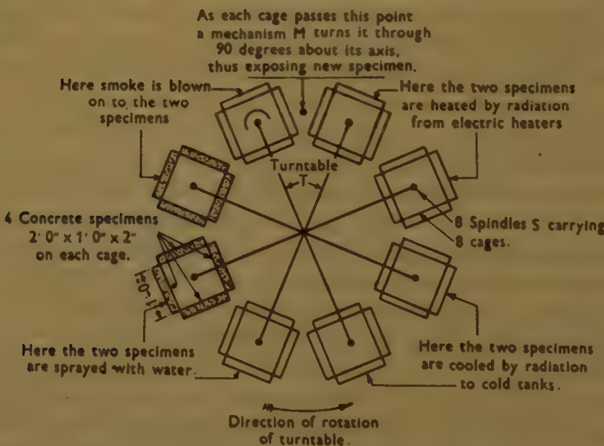
The slabs were de-moulded 24 hours after casting and were then cured r 4 days under damp sacks and thereafter in air until ready for exposure

[1] For a detailed description of the preliminary continental survey reference should made to "Surface Finishing of Concrete—A Survey of Continental Practice," by F. Denaro and J. G. Wilson, issued by the Cement and Concrete Association, ndon.

at 28 days. Both sides of each slab were finished in the same manner. All slabs and surface finishes were produced in quintuplicate, a specimen of each type being exposed to weathering in London and in two industrial towns in the north of England, the finished surfaces facing north and south. Of the remaining two specimens of each type, one has been kept under controlled conditions at the Building Research Station as a reference specimen, and the other has been exposed to artificial weathering in a machine designed specially for the purpose.

The periodical examination of the exposed slabs which were mounted in frames in the manner indicated in *Fig. 1*, has been made by the usual visual and photographic methods, supplemented by another method in

*Fig. 2.*




Diagrammatic Arrangement of Artificial Weathering Machine.

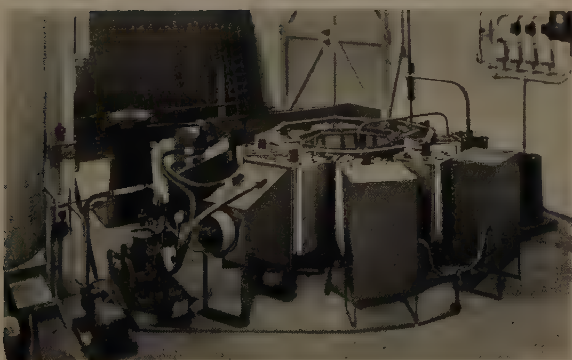
which the light reflected from the surface of an exposed slab is measured by means of a photoelectric cell. Since this quantity depends so much upon atmospheric conditions at the time of making the observations, a similar measurement is taken at the same time of the light reflected from a standard Bristol board. This latter measurement is then used to correct the readings on the slab to a standard condition of lighting, the corrected values being taken as a measure of the "dirtiness" of the surface under consideration.

The artificial weathering-machine, a diagrammatic plan of which is shown in *Fig. 2*, consists of a turntable T, carrying on its periphery eight vertical spindles S. Symmetrically disposed, and free to rotate about each of these spindles, are mounted four concrete specimens with their long edges vertical. Thirty-two specimens may thus be accommodated. About the turntable is arranged apparatus by means of which two of the eight

*Fig. 1.*

CONCRETE SLABS EXPOSED TO WEATHER ON ROOF OF BUILDING IN LONDON.

*Fig. 3.*

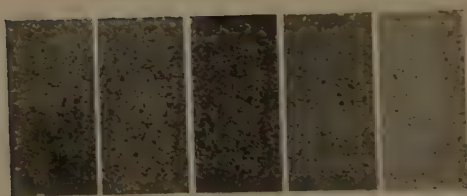


GENERAL VIEW OF ARTIFICIAL WEATHERING MACHINE.

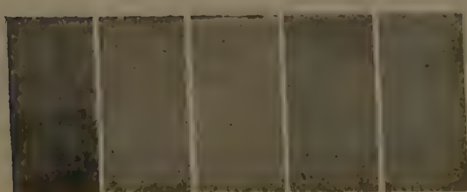
*Figs. 4.*


Untreated Surface Direct from Forms.

Surface Scrubbed.



Surface Bush-Hammered.



Surface Ground.

1. Artificially weathered, top half of slab scrubbed with water after exposure.
2. Exposure in industrial town A.
3. Exposure in industrial town B.
4. Exposure in London.
5. Reference slab.

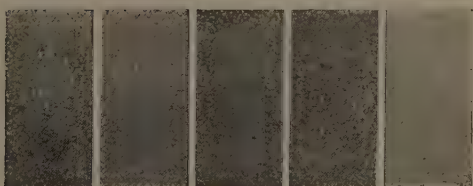
1 : 2 : 4 CONCRETE WITH GRANITE AGGREGATE AFTER EXPOSURE FOR 1 YEAR.

*Figs 5.*

1 2 3 4 5

Untreated Surface Direct from Forms.

Surface Scrubbed.



Surface Bush-Hammered.

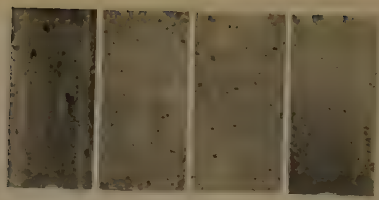
Surface Ground.

1. Artificially weathered, top half of slab scrubbed with water after exposure.
2. Exposure in industrial town A.
3. Exposure in industrial town B.
4. Exposure in London.
5. Reference slab.

1 : 2 : 4 CONCRETE WITH MARBLE AGGREGATE AFTER EXPOSURE FOR 1 YEAR.

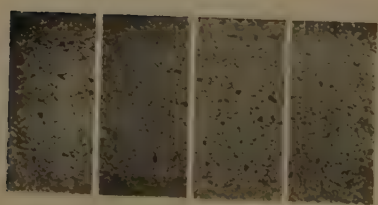
*Figs. 6.*

1 2 3 4



Untreated Surface Direct from Forms.

Surface Scrubbed.



Surface Bush-Hammered.

Surface Ground.

1. Portland Stone Aggregate. 2. York Stone Aggregate. 3. Granite Aggregate. 4. Marble Aggregate.

1 : 2 : 4 CONCRETE AFTER EXPOSURE IN LONDON FOR 3½ YEARS.

outward-facing specimens may be subjected to the action of smoke, two to a water-spray, two to cold, and two to heat.

When in operation, the cycle of events is as follows :—

The outer eight specimens are exposed to the weathering conditions mentioned above for a period of 3 hours, at the end of which the turntable rotates through an angle of 90 degrees, thus transferring the specimens from the action of one weathering agent to that of the next. When the outer eight specimens have been exposed to all four weathering agents for the prescribed period of 3 hours, a mechanism M comes into operation, which, as the turntable revolves, turns each group of specimens through 90 degrees about its own axis, thus exposing a new set of specimens on which the weathering cycle is repeated. The action of the machine is entirely automatic and each of the thirty-two specimens is subjected to a complete cycle of weathering once in 48 hours.

A view of the machine is shown in *Fig. 3*.

Specimens exposed to natural weathering were examined every 3 months during the first year of exposure; thereafter the examinations have been carried out twice yearly. Specimens exposed to artificial weathering in the accelerated weathering-machine have been examined after every six complete cycles of exposure.

As the degree of weathering and discolouration of the concrete has been found to vary under different conditions of natural exposure, it is at once apparent that the purely arbitrary conditions selected for an artificial weathering cycle cannot satisfy all the conditions likely to be experienced under natural conditions.

A photographic record of the appearance of the slabs of concrete prepared with crushed granite and white marble aggregate after exposure to natural weathering for one year and to artificial weathering for sixty cycles, is given in *Figs. 4* and *5*, and *Fig. 6* illustrates slabs prepared with the same aggregate and with crushed York stone and crushed Portland stone, after $3\frac{1}{3}$ years' exposure in London. In *Fig. 7* are plotted curves showing the change in light reflexion from the surfaces, at various ages, of the concrete exposed in London. The observations are typical of those obtained in towns A and B, except that in town B the surfaces generally were more discoloured.

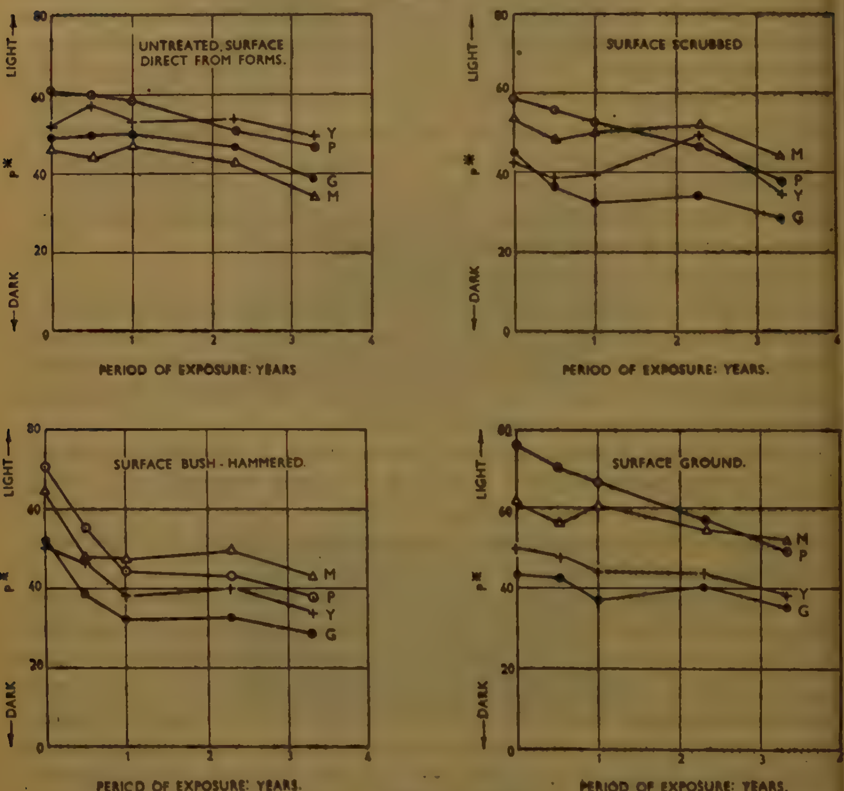
## General Conclusions.

From the experimental investigations and from the survey of structures it has been possible to draw a number of conclusions. These will be dealt with under the following main headings :—

1. Control of mix.
2. Design of formwork.
3. Method of placing.

4. Construction joints.
5. Types of finish.
6. Conditions of exposure.

*Figs. 7.*




Y = York stone aggregate.
P = Portland stone aggregate.
G = Granite aggregate.
M = Marble aggregate.
P * = Amount of light reflected from the surface expressed as a percentage of that reflected from a standard Bristol Board under the same condition of lighting.

DARKENING OF CONCRETE SURFACES DURING EXPOSURE IN LONDON.

1. *Control of the mix.*

Whatever the subsequent treatment of the surface of the concrete is to be, the first essential is to produce concrete which, when the formwork is struck, will reveal a surface of uniform colour, free from honeycombing, defective construction joints, and other blemishes. Subsequent treatment, such as tooling or patching of the surface, will not mask defects of

this type. The concrete must therefore be dense and well compacted, uniform, and free from segregation, and to achieve this the cement-content, water-content, and grading of the aggregate will need to be rigidly controlled. No satisfactory finish to the concrete can be obtained without such control. Proper cover to the reinforcement must be provided in order to avoid the possibility of subsequent staining of the surface by rust. If the surface is ultimately to be tooled, allowance must be made for the reduction in cover to the steel due to this operation.

Since the colour of the concrete varies with the quantity of cement used, the amount used in successive batches must be kept constant. An excess of cement in any section of the work is liable to lead to troubles with shrinkage, cracking, and subsequent disfigurement.

Variations in water-content may also cause a disparity in colour between successive batches, and, if the quantity of water is excessive, crazing of the concrete surface will tend to develop more quickly. The concrete must, however, be sufficiently workable that it can be placed readily without the formation of honeycomb patches. Very wet mixes segregate readily, resulting not only in variations in colour and texture throughout the depth of a lift, but also in the accumulation of laitance scum at the top of the lift. This latter tendency will be referred to later when considering construction joints.

To ensure uniform quality and to produce a surface uniform in colour and texture, the aggregate should be of one quality throughout the work. The aggregate should be of uniform grading and free from clay, silt, or adherent films, since these materials affect very markedly the colour of the concrete. All batches of the aggregate should therefore be obtained from the same source. Some gravel aggregates contain particles of pyrites, which on subsequent oxidation lead to rust-marks on the concrete. Such an instance is shown in *Fig. 8*.

As a general rule, if concrete is to present a good appearance, it may be necessary to adopt special mixes, using standard-size, or small-size coarse aggregate, and possibily a high proportion of sand and even more cement in order to obtain the result required.

2. *Design of formwork.*

Special consideration should be given to the design of the formwork if a good finish to the concrete is desired. The good appearance of a monolithic concrete structure more often than not depends more upon the treatment of the formwork pattern than upon any other single factor. The pattern left by well-designed formwork often provides an excellent finish to the concrete; but the result of carelessness in the design of the formwork, for example, the haphazard use of horizontal boards in one place with vertical boards in another, with no thought as to the pattern that will be left upon the concrete, is unpleasant; and subsequent attempts to obliterate the unsightly board-marks, by tooling or by any other method,

will not necessarily prove satisfactory. Vertical and horizontal boards can, however, be carefully combined to produce special patterns.

Tight formwork, in true alignment is essential to good work; insecure and improperly braced forms will produce uneven surfaces. If the formwork is insufficiently stiff, the boards may bulge slightly at the bottom of a lift where the pressure of the wet concrete is greatest, and unless the degree of bulge is deliberately controlled this will result in the concrete projecting at this point in an unsightly manner. The projecting concrete may be chipped away and the surface patched, but the repair will always be apparent and will become more noticeable as the concrete ages. An example of this defect is illustrated in *Fig. 9*. Cases have been observed where the forms have been allowed to bulge by a definite amount and in a predetermined manner, so that the regular bulges resulting from this procedure have provided a good pattern of light and shade on an otherwise drab and uninteresting surface. Wire form ties should be forbidden, since the wire, if left in the concrete, causes unsightly rust-stains.

Boards should be matched in width. Narrow boards usually give better results owing to less warping; tongued and grooved boarding gives excellent results, although the tongues of the boarding may tend to break during stripping unless considerable care is taken. For this reason it may be preferable to have the boards made up into panels. Square-edged boarding is equally effective if care is taken to ensure that the boards are held together tightly so that the fine mortar from the concrete will not escape through the joints. Wrought boards are usually advantageous, since they require less cleaning than unwrought boards and, when the formwork is struck, leave the surface of the concrete more easily. Three-ply and five-ply linings, if available, offer considerable advantages over other types of formwork. Further reference to the use of this material is made later.

Old and new boards used on the same work produce very marked contrasts in tone on the surface of the concrete where each board has been. Some boards, and particularly many old boards, are more absorbent than others. The formwork oil and water from the concrete soak into them more readily, the surface is often rougher, and the concrete tends to adhere, so that the boards do not come away cleanly. New or little-used boards, on the other hand, retain the formwork oil on the surface, are less absorbent, and come away cleanly from the concrete. *Fig. 10* illustrates the effect of using boards of unequal width and of different absorptive properties. Boards should also be of equal thickness, or the surface will have a very uneven appearance.

Care should be taken in the positioning of the vertical joints in the boarding if these are to be given equal prominence with the horizontal joints; they should be staggered, with alternate joints lined up one above the other. This point is very often overlooked; yet it is a very important factor in the appearance of the building.

*Fig. 8.*

IRON STAINING OF SURFACE DUE TO INCLUSION OF PYRITES IN AGGREGATE. SIMILAR STAINING MAY BE CAUSED BY RUSTING OF REINFORCING BARS.

*Fig. 9.*

EFFECT PRODUCED BY THE USE OF INSECURE FORMWORK.

*Fig. 10.*

NEW AND OLD BOARDS OF VARYING WIDTH PRODUCE AN UNSIGHTLY SURFACE.

*Fig. 11.*

CONSTRUCTION JOINTS SO DISPOSED AND SPACED IN A REGULAR MANNER THAT THEY BEAR SOME RELATION TO OTHER ARCHITECTURAL FEATURES OF THE STRUCTURE.

If the timber is not well seasoned there may be a tendency for the boards to shrink and for the joints to open, particularly if concreting is long delayed. If this should happen, it is desirable to soak the forms so that the boards swell and the joints close before the concrete is deposited.

The standardization of formwork and the use of commercial sizes of materials leads to economy and simplicity of design. The design of the forms should be such that they can be easily removed and used repeatedly if required; if removal is difficult, or is done carelessly, the concrete will be marred by spalling at the edges and corners. All arrises and internal corners should be chamfered, not only to facilitate easy removal of forms, but also to improve the general appearance of the work.

3. *Method of placing.*

In order to reduce the possibility of segregation during transportation and handling, the mixing-plant should be installed as near as possible to the point where the concrete is being deposited. In some circumstances it might be advisable to insist upon remixing of the concrete, on a banker board, before finally depositing it in the forms.

The concrete should be deposited gently into its final position as quickly as is practicable, but not allowed to find its own level by being caused to flow from too great a height. It should be worked into place and thoroughly compacted by hand or by mechanical vibration. Too much spading on the inside surface of the forms will tend to accumulate too thick a layer of mortar. The consistency of the mix may also need to be varied, particularly if a high percentage of steel is present, but in any case the slump of the mix to be used in the various portions of the work should be clearly stated in the original specification. When the concrete is finally in position it should not be subjected to disturbance other than such as is incidental to compacting by vibration. Concreting should be carried out continuously between and up to the construction joints, the position of which should be predetermined. It is important that all concrete deposited in the forms should be maintained reasonably level in between planes of stoppage formed by vertical stopping-off boards or other vertical faces.

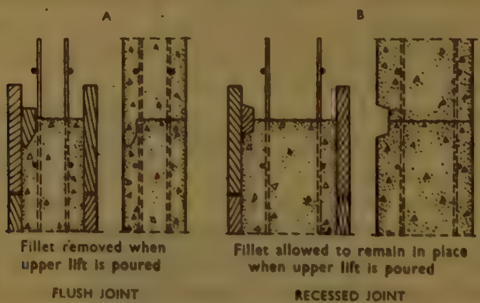
As in all concrete work, exposed surfaces of freshly-deposited concrete must be protected from the weather, and particularly from the effects of frost, of drying winds, or of the sun. It should also be protected against rain, since an accumulation of water on the surface may result in the formation of a porous layer to which the concrete in the next lift will adhere very poorly.

4. *Construction joints.*

However carefully construction joints are made they will inevitably appear on the surface of the concrete as strongly-marked lines. In the case of reinforced concrete, badly-made construction joints may be

permeable, leading to rusting of the reinforcement and to the formation of brown stains at the joint lines. The position of all construction joints should therefore be carefully predetermined and the work planned so that the precise position of each joint is shown on the working drawing and is adhered to: the full co-operation of all who execute the work will be needed to carry this out. The joints should be disposed and spaced in a regular manner so that they bear some relation to the design of the building and to such features as sills and lintels of openings. A good example of this is illustrated in the view in *Fig. 11*, of the swimming pool at Wembley, in the construction of which Sir Owen Williams, M. Inst. C.E., obtained regularly-spaced construction joints throughout the entire job by simplifying the formwork by very rigid adherence to a unit of construction of 2 feet 9 inches, so that it was possible to have a vertical shutter of 2 feet

*Figs. 13.*




FILLET CONSTRUCTION JOINTS.

9 inches with horizontal shutters of 8 feet 3 inches which were omitted wherever a window came, the window also being 8 feet 3 inches long.

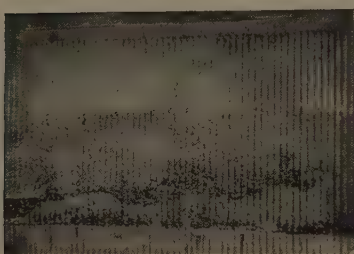
The haphazard distribution of joints will be very unsightly, and attempts to conceal them by subsequent treatment of the surface will not mask their presence. Joints may, however, be concealed at string courses and cornices. An excellent example of the latter method is to be seen in *Fig. 12*, which shows a portion of Twickenham bridge over the river Thames. Here Mr. Maxwell Ayrton adopted the very ingenious method of concealing the construction joints by inserting string courses of roofing tiles which were subsequently bush-hammered with the rest of the work. The inset lamp is of precast concrete with scrubbed surface.

The first essential is to obtain clean, regular, truly horizontal and vertical lines, and this can best be achieved by nailing a fillet on the formwork and by stopping off the lift against the fillet, as shown in *Fig. 13.* The fillet is removed before the next lift is poured and the new concrete, flowing into the recess so formed, gives a clean straight joint. From the architectural point of view, it may sometimes be advantageous to accentuate the construction joints to provide an elevational feature, in

*Fig. 12.*

CONSTRUCTION JOINTS CONCEALED BY THE INSERTION OF STRING COURSES OF ROOFING TILES WHICH WERE SUBSEQUENTLY BUSH-HAMMERED WITH THE REST OF THE WORK.

*Fig. 14.*



ONE LIFT OF POORLY PLACED CONCRETE MAY DISFIGURE PERMANENTLY THE WHOLE STRUCTURE. HONEYCOMBED POCKETS CANNOT BE SUCCESSFULLY MASKED BY SUBSEQUENT PATCHING.

*Fig. 15.*

SUBSEQUENT TREATMENT OF THE CONCRETE BY TOOLING OR OTHER MEANS WILL NOT CONCEAL FAULTY CONSTRUCTION JOINTS.

*Figs. 16.*

(*a*)

(*b*)

Complete separation of the adjacent lifts is apparent.

TWO EXAMPLES OF FAULTY CONSTRUCTION JOINT.

which case the fillet may be left in when the new concrete is poured. The result will then be a deep groove running continuously along the line of the construction joints. The fillets should be shallow, to avoid wastage of concrete, and be V-shaped so that they will come away cleanly from the concrete; the resulting recessed grooves are bevelled outwardly at the top and bottom, or alternatively horizontal at the top and bevelled at the bottom. Horizontal ledges at the bottom of grooves and mouldings tend to collect dirt and grime and should be avoided. Acute angles in mouldings should be avoided, as it is very difficult to fill these properly with concrete.

In some cases the construction joint may be a plane of weakness, but tests at the Building Research Station [1] have shown that it is possible to produce joints as strong as the concrete itself. Laitance scum, if allowed to collect in the upper surface of a lift of concrete, renders the top layer weak and permeable. The use of excessively wet mixes must therefore be avoided. Trouble may also occur at the bottom of the lift, on the upper side of the joint, owing to segregation and honeycombing resulting from the use of under-sanded and harsh-working mixes, too much mixing water, or a deficiency of cement. Insufficient compaction, or allowing the concrete to flow along the forms to find its own position, also results in segregation and honeycombing. Honeycomb patches weather very badly and become more prominent as time passes.

Defects of the type described above are illustrated in *Fig. 14*, which shows a portion of a wall where the control during the placing of the middle lift has been relaxed, with unfortunate results. No patching or tooling of the surface or the use, as in the example illustrated, of a serrated surface will hide such defects, but they will remain an eyesore as long as the building lasts.

In order to ensure good bond at a construction joint, the upper surface of the set concrete should be thoroughly roughened and the surface thus exposed thoroughly washed and saturated with water to remove loose particles, steel "snippets," etc. A layer of mortar of similar proportions to that incorporated in the concrete should then be applied to the wetted surface and the new concrete placed immediately upon it, care being taken to ensure that the concrete is well compacted to obtain intimate contact with that already in position. The importance of roughening the surface of the old concrete cannot be over-estimated. It is probable that, even without the application of a layer of mortar, the exposed aggregate on the roughened surface of the old concrete would provide a more efficient key for the new concrete than would a layer of mortar applied directly to an unroughened concrete surface. However, the combination of both roughening the surface and applying mortar, as indicated above, should achieve satisfactory results.

[1] B.R. Bulletin No. 9, "Bonding New Concrete to Old", and B.R. Special Report No. 16, "Construction Joints in Concrete."

*Fig. 15* shows an instance where the construction joints have been placed in a position which has resulted in disfigurement to the elevation. *Figs. 16* (*a*) and (*b*) show that subsequent tooling of the concrete surface will not conceal the presence of faulty construction joints. *Fig. 17* shows an instance where, owing to faulty construction joints in a retaining wall, seepage of moisture from behind the structure has occurred, resulting in the development of unsightly patches of efflorescence. This seepage can be reduced or eliminated by the insertion of longitudinal keys in the joints.

5. *Types of finish.*

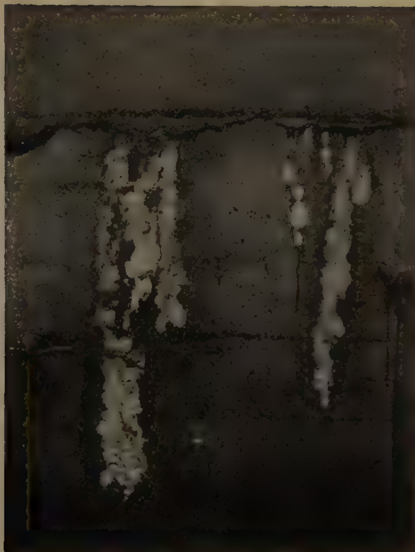
(i) *Board-marked textures.*—Whether concrete structures should be left with a textured surface or should be finished smooth with all board marks obliterated must remain largely the choice of the designer. Each type has its merits and each can be used successfully in its appropriate place. Excellent examples of board-textured finishes exist in Great Britain and on the Continent, where they seem, in general, to have been preferred to entirely smooth finishes. In America, on the other hand, the general tendency until recently has been towards the entire elimination of board marks and the adoption of broad smooth surfaces in order to gain striking architectural effects. This has been achieved by the use of linings to the formwork; more detailed reference to this point will be made later.

In the opinion of the Author, a carefully planned board-textured surface is particularly suited to engineering structures. Two good examples are illustrated in *Figs. 18* and *19*. The first shows the lower or underside of the Tranebergssund bridge, Stockholm, and indicates how form linings may be used to produce a surface texture that is a true expression of the method of building in concrete. The second (*Fig. 19*) shows one end of the roof of an omnibus shelter at Berne, Switzerland, and also illustrates how the use of good formwork is amply repaid by the results achieved.

Another notable example of board-textured finish may be seen in the ceiling and columns of the Assembly-Hall at the Merchant Taylors School, Rickmansworth (*Fig. 20*). Here Mr. William G. Newton, the architect, left the concrete exactly as it was after the removal of the shuttering. The colour is attractive, bearing a faint rustiness on the grey arising probably from the metal on the "tins" used in the shuttering. The "board-mark" texture is of two kinds. That on the main beams is from wood boards, and that in the flat panels is the results of small ridges which come at the junction of the "tins." Actually in the last two bays nearest the stage the soffit of the panels is faced with an acoustic building board, and the lines have been repeated on these panels by means of paint so as not to break the continuity of the pattern. All the other markings elsewhere on the ceiling are natural, and arise out of the method of construction.

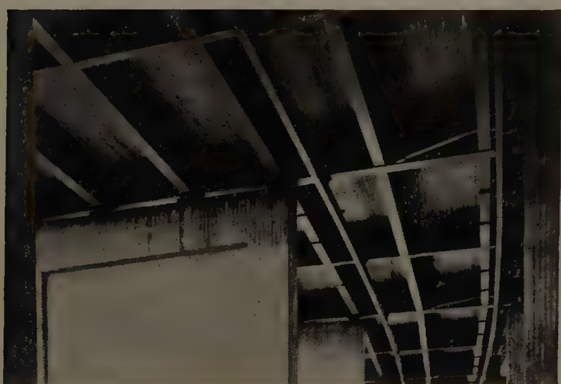
Sometimes it is desirable to keep the board pattern subdued, in

*Fig. 17.*



SEEPAGE THROUGH FAULTY CONSTRUCTION JOINTS MAY PRODUCE UNSIGHTLY PATCHES OF EFFLORESCENCE.

*Fig. 18.*



THE UNDERNEATH SIDE OF THE TRANEBERGSSUND BRIDGE, STOCKHOLM. AN EXAMPLE OF EXCELLENT FORMWORK.

*Fig. 19.*

THE ROOF OF A BUS SHELTER AT BERNE, SWITZERLAND, SHOWING THAT THE BOARD MARKS LEFT BY CAREFULLY DESIGNED FORMWORK ARE NOT DETRIMENTAL TO THE FINAL APPEARANCE OF THE STRUCTURE.

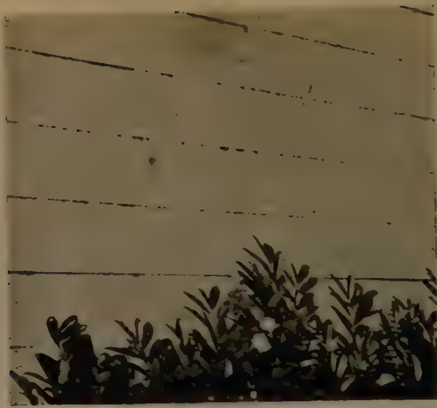
*Fig. 20.*

MERCHANT TAYLORS SCHOOL. THE ASSEMBLY HALL WITH UNTREATED CONCRETE ROOF.

*Fig. 21.*

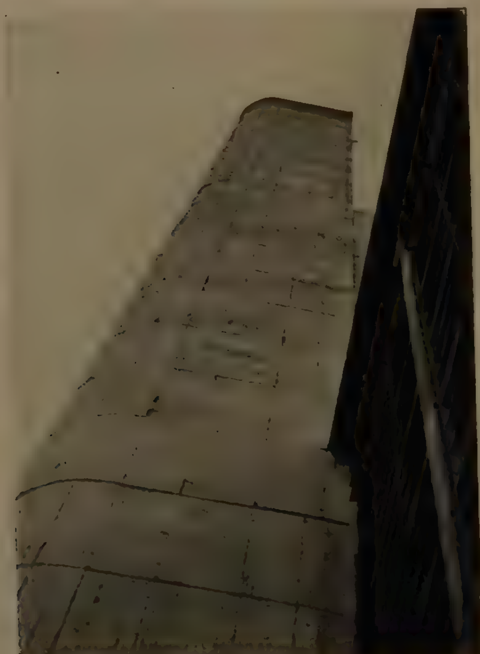
MARLBOROUGH COLLEGE LABORATORIES. THE ACCENTUATION OF BOARD LINES CONCEALS THE CONSTRUCTION JOINTS AND RELIEVES THE MONOTONY OF OTHERWISE PLAIN SURFACES.

*Fig. 22.*



THE PROJECTING FINS OF CEMENT, CAUSED BY SLIGHT LEAKAGE AT THE JOINTS BETWEEN BOARDS, MAY AS IN THE CASE ILLUSTRATED BE LEFT AND SO RELIEVE THE MONOTONY OF THE SURFACE.

*Fig. 23.*



AN EXCELLENT EXAMPLE OF THE USE OF NARROW VERTICAL LATHS I FORMING THE CONCRETE SHUTTERS. NOTE THE METICULOUS CAR TAKEN TO LINE UP THE FORMWORK, SO THAT JOINTS LINE UP BOT VERTICALLY AND HORIZONTALLY.

which case all projecting fins can be removed by chiselling and imperfections can be rubbed down flush with carborundum stone or other approved means, the grit and dust resulting therefrom being thoroughly washed off with clean water. Then, as a separate operation, a 1 : 1 to $1\frac{1}{2}$ Portland cement and clean sand mixture is worked into the pores over the whole surface with a fine carborundum float in such a manner that no more material is left on the concrete face than is necessary completely to fill the pores, so that a uniformly smooth and dense surface is finally presented.

On the other hand, it may be desired to accentuate the board-lines to subdivide the surface into a well-marked pattern. This may be achieved by the use of tongued and grooved match-boarding with chamfered edges placed inwards towards the concrete. An excellent example of this form of treatment is the Marlborough College laboratories (*Fig. 21*), of which Mr. William G. Newton was the architect. Here two things were done: firstly, the laitance was brushed off the external walls with a hard broom as soon as practicable after each section of shuttering was taken down, and secondly, in order to distract attention from the rather unsightly and irregular horizontal junctions of each day's work, a shallow fillet (not more than $\frac{5}{8}$ inch projection), produced by chamfering the edges of adjacent boards in the shuttering, was carried all round the external walls. No attempt was made to make this fillet particularly sharp and accurate, nor was an occasional roughness in the fillet considered a drawback. Theale gravel aggregate was used and the mix was tinted slightly so that the final result was a fawn colour with the black and white of the Theale aggregate lending variety here and there. After 10 years the building still looks satisfactory.

Where very careful alignment of the horizontal ridges is required, precautions should be taken to guard against movement of the timber formwork due to moisture absorption. This can be achieved by treating the timber with formwork oil or shellac. Weatherboarding may be used to produce the same effects. *Fig. 22* illustrates a concrete wall where the architect has intentionally left the cement fins produced by a slight leakage of the mortar through the joints of square-edged boarding, in order to relieve the monotony of the surface.

Attractive finishes with parallel mouldings at close centres can be obtained by the use of reeded shutters. An excellent example of the use of narrow vertical laths is given in *Fig. 23*, which shows the chimney of the central heating building adjacent to the Swiss Federal Technical University at Zurich. The careful control of the height of each lift and the careful alignment of the formwork even down to the narrow laths should be noted.

From the architectural and aesthetic points of view, however, it may sometimes be desirable to relieve the monotony of large areas of concrete by eliminating the board-marks altogether, treating certain portions of the work by mechanical or other means. The various types of finish that are

available and the methods by which they can best be obtained are described below.

(ii) *Smooth finishes.* (a) *Plywood and wallboard linings.*—Smooth finishes without visible joint-lines, or with joint-lines showing only at wide intervals, are normally produced by lining the formwork with metal sheets, plywood, or compressed fibre boards, treated with oil or lacquer to prevent the concrete adhering. Three main types of plywood are available. The first type, which is not very suitable for concrete work and can be used only once or twice, is that in which water-soluble glue has been used. The plies tend to separate when the plywood becomes wet. The second type, which is suitable for use as concrete formwork, is manufactured with highly water-resistant casein base cold glue. The face veneers of the sheets are thicker than those of the first type, and in consequence they can resist more abrasion and have a longer period of use. In the United States of America this type has to conform to the specification of the National Bureau of Standards for Concrete Form Plywood, and each sheet marketed bears a grade mark. The third type is an exceptionally high-grade plywood manufactured by using a cresylic formaldehyde synthetic resin binder, hot pressed and tempered. This has been highly developed in America, where panels of the material are used with standardized metal-framed form units, apparently with considerable success. The increased cost of the product is said to be offset by its long period of service.

Plywood is made in thicknesses ranging from ⅛ inch to ¾ inch, and the overall dimensions range from 3 feet to 10 feet in length and from 3 feet to 5 feet in width, although the largest size readily obtainable is probably 8 feet by 4 feet. It is important for the sake of appearance that only one standard size of sheet should be used on any one job. A standard size 8 feet long and 4 feet wide is used successfully in the United States, where some very fine buildings have recently been erected with plywood forms, the most notable being the hangars and dormitories at the Randolph airport, San Antonio, Texas [1], the Griffith observatory in California [1], and the Armory at Olympia, Washington [2].

Plywood less than ⅝ inch thick needs to be supported on studding to prevent it deflecting, whilst if it be less than ⅜ inch thick the plywood should be backed up solidly, and nailed along the edges with flat-headed nails spaced 4–6 inches apart and with at least one to every square foot of surface-area, so that the plywood will not bulge. All plywood panels must be of exact dimensions, with their edges straight and true so that they abut very closely. Any cracks that may develop in the joint should be filled with white lead, putty, or plaster of paris filler. After the filler has dried the filled joints should be carefully sanded and given an added coat of formwork oil or lacquer.

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[1] "Plywood Form Work is Important Factor in Architectural Concrete." *Concrete*, May 1940.

[2] "Plywood Forms and Architectural Concrete." *Concrete*, February 1940.

The useful life of plywood, or of any other type of sheet lining, depends largely upon the care used in handling during stripping and in storage while not in use, and also to a great extent upon the degree of standardization of the units. The panels must not be prised from freshly-deposited concrete by using metal wedges and metal tools. If wedges must be used they should be of wood, and any easing of the plywood to release it from the concrete should be accompanied by light tapping.

The panels of sheeting must not be dropped to the ground on stripping, or be trodden on, but should be carefully cleaned with wide and flat paint scrapers, and stacked evenly on a dry and level site under shelter, or protected from the weather by covering with tarpaulins.

Pattern lines may be formed on the concrete surface by nailing hardwood strips over the horizontal joints between plywood panels. These lines may be used to hide construction joints, in which case concreting must be carried on continuously up to the middle of the strip.

Similar precautions should be taken when using compressed fibre-boards as form linings. The material can normally be used three or four times.

(b) *Treatment of surface.*—On removal of the forms any small holes on the surface of the concrete may be filled. The surface should be wetted and a grout composed of 1 part of cement and 1 to 1½ part of fine sand, to give a mix of creamy consistence, applied uniformly to the surface with a stiff brush so as to fill the holes completely. When the grout has partially set, the excess can be scraped from the surface with a trowel; and when the surface of the concrete is dry, it should be rubbed vigorously with a piece of rough cloth or hessian, to remove any dried grout remaining on the surface. No patching should be allowed unless carried out as detailed later.

(c) *Absorptive linings.*—Most of the holes on the surface of concrete are caused by entrapped bubbles due to the use of non-absorbent linings; vibration methods of compaction tend to reduce them, but they still persist. When the concrete is cast against absorbent linings the holes can be almost entirely eliminated. This fact has led to the recent development in America of special absorbent linings, which will come away cleanly from the concrete [1]. Tests by the Bureau of Reclamation at Denver [2,3] indicated that considerable improvements could be effected, both in appearance and quality of concrete surfaces placed against vertical and sloping forms, by lining the forms with highly absorptive wall-boards about ½ inch thick, made of ground cane, wood-pulp or similar materials. When concrete was placed against forms of this type, practically all pitting and voids so often found on such surfaces were eliminated. Similar results have been obtained by using muslin-covered absorptive insulating boards [2].

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[1] W. R. Johnson, "The Use of Absorptive Wall-boards for Concrete Forms." J. Amer. Concrete Inst., vol. 12, No. 6. June 1941.

[2] C. O. Crane, "Find Way to Eliminate Voids under Forms on Concrete Surface." *Concrete*, March 1940.

[3] E. N. Bidel and R. F. Blanks, "Absorptive Form Lining. J. Amer. Concrete Inst., vol. 38, No. 3. Jan. 1942.

(d) *Special linings.*—Various decorative effects can be produced by lining the formwork with special sheets. In *Fig. 24* (*a*) the surface produced by using crêpe rubber is shown, whilst *Fig. 24* (*b*) shows that produced by using serrated cardboard. The rubber sheeting can be used many times, but the cardboard cannot normally be used more than once. The chief objections to the use of sheet materials are the difficulty of fixing the sheets to avoid creasing, and of concealing joints. For these reasons this type of treatment is probably suitable only for small areas, such as panels and margins.

(e) *Patching.*—It is very difficult to patch concrete satisfactorily, and the patches become more apparent as the concrete ages. If proper precautions are taken during mixing and deposition no honeycombing of the concrete should occur, but if it does the defective concrete must be cut out, the edge of the areas being cut perpendicular to the surface to avoid feather edges to the patch. The surface to be patched should then be well brushed with a thin grout, composed of 1 part of cement and 1 part of sand, which should be followed immediately by a mortar of similar proportions to that used in the concrete. This mix should be of a stiff consistence and should be pressed into the cavity by hand, a wood float being used for the final compaction of the mass. The surface of the mortar should be left slightly higher than the surrounding concrete and after an hour or two, depending upon the weather, the patch should be finished with a wood float flush to the surface of the wall, and finally wiped with a dry cloth: a steel float should not be used. Holes left by tie-rods must be filled for the whole thickness of the wall, in order to minimize damp patches.

Normally patches appear darker than the surrounding concrete—possibly owing to the presence on their surface of less cement laitance, but this defect may be remedied by adding, say, 10–20 per cent. of white Portland cement to the patching mortar, the exact quantity required being determined by trial.

Streaks on the face of the concrete caused by leakage of concrete from the formwork may be removed by using a fine hone, with plenty of water. An examination of smooth concrete surfaces after exposure has shown that they tend to become patchy and streaky, owing mainly to the flowing or dripping of rainwater down the surface. In Germany and Switzerland flashings are provided at window-sills and on projections from the vertical face so that dripping rainwater is not allowed to spoil its appearance.

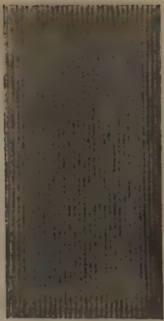
Crazing of the surface is also much more apparent on smooth surfaces than on rougher ones, and a more satisfactory finish may be obtained by exposing the aggregate by grinding with carborundum blocks operated by hand, or, better still, by electrically-driven disks. This process has been found to produce surfaces differing considerably in light reflection, according to the type of aggregate used, but the differences become much less marked as the concrete ages.

*Figs. 24.*

(*a*)

Results obtained by using Special Rubber Sheeting.

(*b*)



Results obtained by using Corrugated Cardboard.

SURFACES PRODUCED BY USING LINING SHEETS FIXED TO THE FORMWORK.

*Fig. 25.*

MERCHANT TAYLORS SCHOOL. OCTAGONAL CONCRETE COLUMN CLEANED WITH CARBORUNDUM AND WAX POLISHED.

*Fig. 26.*

THE BRIDGE AT FRIBOURG, SWITZERLAND—AN EXCELLENT EXAMPLE OF THE USE OF A BUSH-HAMMERED SURFACE. THE NARROW MARGIN LEFT AT THE ARRISES SHOULD BE NOTED.

Some very pleasing effects can be obtained by this method, particularly for internal decorative purposes. Its application to the octagonal columns in the vestibule to the Great Hall at the Merchant Taylors School is shown in *Fig. 25*. Here the concrete was cleaned down with carborundum and then wax polished, and it resembles Hopton Wood stone. The horizontal joint marks were then cut.

(iii) *Exposed aggregate.*—Many interesting surface textures can be obtained by exposing the aggregate by removing the cement skin from the face of the concrete. By using specially selected aggregates some very pleasing colour effects may also be obtained. The methods of exposing the aggregate are :—

(a) Tooling by bush-hammering, picking, or working up with masons' tools, operated either electrically, pneumatically, or by hand.
(b) Scrubbing.
(c) Sand-blasting.
(d) Using surface retarders.

Exposure tests have shown that surfaces with exposed aggregates weather more uniformly than others. The rough surface obtained also makes for a more interesting play of light and shade than a smooth surface, as there is considerable reflexion of light, which imparts a sheen to the surface.

It has already been stated that subsequent treatment by tooling or other means only partially succeeds in concealing the defects of bad workmanship and will not remove the contrasts in colour between concrete made with aggregates of different type and grading, or between mixes of different proportions; the differences are often accentuated by tooling. The size of the aggregate and its distribution should therefore be maintained uniform throughout the concrete.

(a) *Tooling.*—The concrete should be thoroughly hard before any attempt is made to tool the surface. Special appliances in the form of electrical and compressed-air bush-hammers are available for this work. Bush-hammering or "sparrow-pecking" usually gives a rough and deeply-cut surface, and when this method is used care should be taken to leave a narrow margin at the edges and corners of the area treated, since if carried too near the edge danger of spalling the concrete will arise. The margin which is not bush-hammered may be either left untreated or lightly tooled in horizontal or vertical lines. *Fig. 26* illustrates the bridge at Fribourg, Switzerland—a good example of this type of finish—and shows the narrow lightly-tooled margins along the edges of the masses.

Tooled surfaces are popular on the Continent, and many interesting effects are produced by the use of special hammer-heads and chisels devised to give various types of pattern. Used, for example, with a rule, a series of parallel lines can be formed on the surface, to give it a reeded appearance, or the surface may be divided into squares and each square tooled in a

different direction or manner. Examples of these finishes are shown in *Figs. 27* (*a*), (*b*), (*c*). If tooling is to be adopted it will be necessary to increase the depth of cover to the reinforcement.

(b) *Scrubbing.*—Exposure of the aggregate by scrubbing with wire brushes, combined possibly with the use of acid solutions, depends for its success upon the early stripping of the forms so that the concrete can be treated before it attains too high a degree of hardness. Therefore, the method is more suitable as a means of treating precast concrete than monolithic concrete. The surface obtained, however, is pleasing and weathers well. If acid solutions are used, care must be taken to remove all traces of them: this can best be done by washing with a dilute alkaline solution, followed by liberal washing with clean water.

(c) *Sand-blasting.*—Sand-blasting has been tried, but is not very effective, as the tendency is to erode the softer portions of the concrete surface to a greater extent, and so produce a non-uniform appearance. The process is also relatively expensive.

(d) *Surface retarders.*—Various preparations have been marketed in Great Britain and abroad for exposing the aggregate. The preparations are brushed upon the formwork and inhibit the setting and hardening of the film of cement mortar which forms on the surfaces of freshly-deposited concrete brought into contact with it. On stripping the formwork the concrete surface is brushed vigorously with a wire brush, the unset cement skin being easily removed and the aggregate exposed. Some of the solutions are essentially solutions of resinous matter in methylated spirit. Others rely on the presence in the preparation of organic retardants such as sugar. The difficulty experienced in using these retarders is to distribute them uniformly on the forms, and so avoid a blotchy appearance of the concrete surface; moreover care is necessary when compacting the concrete, particularly by vibratory methods, to avoid the removal of the retardant from the surface of the forms. Experiments at the Building Research Station showed that by using a retardant of creamy consistence, containing a high proportion of filler, a more uniform result was obtained.

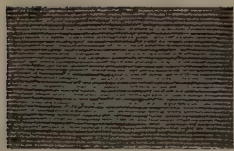
If retarding compounds are used it is necessary to have watertight joints, as otherwise leakage will wash away the compound, and joint-marks, as shown in *Figs. 28* (*a*), will be visible. If the boards are watertight this defect will not occur and the surface will appear as that in *Figs. 28* (*b*).

(iv) *Special aggregates.*—By using special aggregates some attractive and tinted textures can be obtained. Since the aggregates may be costly, and possibly in short supply, it is necessary to restrict their use to the outer skin of the concrete. Several ways have been devised to achieve this, for example:—

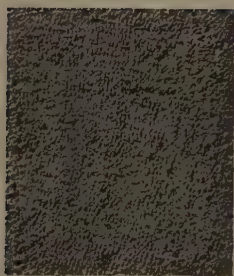
(a) By the use of sliding shutters.
(b) By the "bond transfer" methods.
(c) By using decorative precast slabs as shutters.

*Figs. 27.*

(*a*)



(*b*)



(*c*)

THREE TYPES OF TOOLED SURFACE WHICH HAVE PRODUCED SATISFACTORY RESULTS.

*Figs. 28.*

(*a*)

The effect produced if slight leakage occurs at the joints between boards.

(*b*)

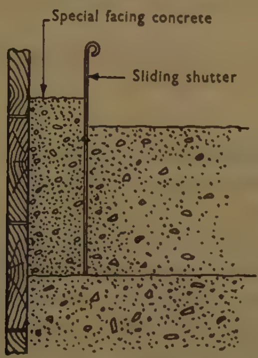
The effect when this fault is rectified.

SURFACES TREATED WITH A CONCRETE RETARDER APPLIED TO THE FORMWORK.

(a) *Sliding shutters.*—In the first method a facing mix of fine concrete with special aggregates, and pigmented, if necessary, is cast simultaneously with the concrete in the main body of the wall, the two mixes being kept separate during placing either by means of a metal lath partition wired to the reinforcement or, as indicated in *Fig. 29*, by a partition plate that can be raised as the forms are filled. A surface mix having shrinkage properties markedly different from that of the backing concrete should be avoided, in order to reduce the tendency to crack formation.

(b) *Bond transfer.*—The "bond transfer" methods have been developed recently in the United States of America by the Portland Cement Association [1], and although the methods have not yet been applied

*Fig. 29.*




SLIDING SHUTTER OR DRAW FORM TO ENABLE A VENEER OF SPECIAL FACING CONCRETE TO BE APPLIED.

commercially to any considerable extent, they have gone beyond the experimental stage and for that reason are mentioned here. The methods consist essentially of lining the main formwork with sheets to which selected aggregates have been stuck. There are two methods, described as "aggregate transfer" and "mortar transfer" respectively, the principal difference between them being in the preparation of the panels and the manner of sticking the aggregate. In the former the facing material is a layer of special aggregate, and in the latter a thin layer of mortar containing the special aggregates distributed uniformly over the form lining material, such as plywood or wall-board, and bonded to it with a special adhesive. After a drying or curing period the panels so formed are fastened to the

[1] R. E. Copeland, "Exposed Aggregate Surfaces for Concrete Walls by the Bond Transfer Method." *Concrete*, March 1939.

formwork. The reinforcement and the inside face forms are then erected and the concrete is deposited. After four to six days, depending upon weather conditions, the forms, and finally the linings, are removed, the aggregate or mortar facing having become securely bonded to the backing concrete. The aggregate on the surface of the concrete is exposed by rubbing with abrasive stones, by sand-blasting, or by bush-hammering. The final treatment consists of cleaning and brightening the surface with dilute acid, followed by a thorough rinsing with clean water.

(c) *Precast slabs.*—Precast decorative slabs may be used as external shuttering bonded to the main concrete, and left in place until the latter has hardened. This method, which eliminates much of the timber formwork, opens up numerous possibilities, although to operate the method economically it would be necessary to accept a fair degree of standardization and restriction in the sizes of precast slabs. The method also presents the great advantage that the surface can be seen and approved before the slabs are erected.

(v) *Colour.*—There are three ways of producing a coloured surface, namely :—

(a) By using coloured aggregates.
(b) By pigmenting the cement.
(c) By applied coverings.

(a) *Coloured aggregates.*—Many types of aggregate are available for these decorative finishes, including natural stones, such as variously coloured marbles, or other rocks and fragments of glazed and unglazed ceramic wares. In order to obtain the full advantage from the use of these special aggregates, they should be of uniform grading and be exposed by wire-brushing or bush-hammering.

(b) *Pigments.*—If pigments are to be used for coloured concrete, great care should be taken to control the proportions of mix. It is difficult to incorporate the pigment properly in the cement by hand : it must be added in small quantities, and preferably during the grinding of the cement. In this way it is possible to ensure that the colour of the cement will be uniform throughout and will not produce streaky or blotchy surfaces. Therefore it is advisable to purchase cements already pigmented.

It is usual to restrict the quantity of pigment to a maximum of 10 per cent. by weight of the cement, but the quantity required will vary according to the colour of the cement being pigmented. White Portland cement can be tinted to give delicate shades of blue, green, yellow, and pink, whilst ordinary Portland cements can be tinted to give darker shades, such as grey, slate, or dark brown.

It is essential that the pigments used should be stable and inert ; the following are the more commonly used :—

| | |
|---|---|
| Lampblack, graphite, manganese dioxide, and black iron oxide | To give shades of grey and slate. |
| Ultramarine | To give shades of blue. |
| Chromium oxide | To give shades of green. |
| Ochre | To give shades of yellow. |
| Red oxide of iron | To give shades of red. |
| Sienna and umber, burnt and raw | To give shades of reddish brown and brown. |

If pigmented cements are used it is essential that the aggregates should be very carefully standardized throughout the work. Variations in the quality of the aggregate will effect colour changes in the concrete, whether the cement is pigmented or not.

(vi) *Applied coverings.*—Applied coverings are really outside the scope of this Paper, but for completeness brief mention will be made of them. They are of various types, including :—

(a) Renderings.
(b) Painting and staining.
(c) Glazing.
(d) Metal-spraying.

(a) *Renderings.*—It is not proposed to deal here with the wide subject of renderings applied to concrete surfaces, apart from mentioning one or two precautions that should be taken. Firstly, the concrete should be roughened to provide a good key by methods already referred to, and the surface should be wetted. The first or "scratch" coat of mortar (1 : 2½ mix by volume) is then applied, preferably by throwing on to secure intimate bond with the concrete surface. The scratch coat is left rough and is allowed to set and dry for a few days, after which it is moistened and the second coat is applied. A true and level surface to this coat is obtained by using a straightedge or floating rule from screeds. The surface is then scratched or combed and a finishing coat is applied.

Another effective way of applying a mortar rendering is by gunning it on to the surface.

There are many types of finishes and techniques for obtaining them, and reference should be made to a Paper by Brady and Denaro [1] for information on the subject: they include pebbledash, spatter-dash, depeter, pargetting, scraped texture, stipple finish, floated finish, tooled finish, etc.

(b) *Painting and staining.*—The painting of concrete surfaces calls for considerable care [2]. Ordinary paint films are very susceptible to attack under damp conditions by the alkalis present in new Portland cement

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[1] F. L. Brady and L. F. Denaro, "External Rendered Finishes. A Survey of Continental Practice." Building Research Bulletin No. 16. H.M. Stationery Office (1938).

[2] H. M. Llewellyn, "The Effect of Building Materials on Paint Films." Building Research Bulletin No. 11. H.M. Stationery Office (1934).

surfaces. Therefore, it is essential that the surface to be painted should be thoroughly dry. An inert priming paint should then be applied: such priming paints are made with special waterproof and alkali-resistant admixtures of oils and gums or synthetic resins, and their effect is to insulate the subsequent coats of paint from the destructive agents in the cement. The decorative coat may be either an oil paint, silicate paint, distemper, or slurry. The oil paint must have been made from one of the alkali-resistant oils, such as tung or Chinawood oil. One such paint, which has been used very successfully in the United States, is described as a Chinawood oil acid-copal resin varnish. Some silicate paints are also available.

It is preferable either to spray the paints on or to apply them with a very stiff brush so as to fill all pinholes.

Staining can be carried out either by depositing the staining material in the pores of the concrete, or by a chemical reaction that may take place between the staining material and the alkalis in the concrete. One method in the former category is to apply creosote, which is obtainable in a variety of shades. In the latter category are chemical compounds, such as ferric iron salt, which, when it comes in contact with the concrete, forms a precipitate of hydrous ferric oxide, which is reddish brown in colour. A wide range of colours, including grey, brown, red, yellow, cream, and green, can be obtained by this treatment.

(c) *Glazing.*—Various proprietary processes are available for imparting glazed finishes, but their application is normally confined to internal use.

(d) *Metal spraying.*—A considerable number of metals, such as aluminium, brass, bronze, copper, iron, lead, nickel, and zinc can be sprayed on to concrete surfaces to provide metallic decoration. A rod of the metal to be deposited is fed mechanically through the oxy-acetylene flame of a special blowpipe, the intense heat melting the metal and the air-blast of 45 lb. per square inch pressure volatilizing it and spraying it upon the surface to be covered. The minute particles of metal cling mechanically to the concrete surface and a thin film of metal is built up.

6. *Conditions of Exposure.*

The effect of the weathering of concrete surfaces varies considerably according to the conditions of exposure. Thus tests have shown, as would be expected, that concrete darkens much more rapidly in an industrial town with a relatively high content of solids in the atmosphere than in one less polluted. In another town, owing probably to a higher acid-content in the atmosphere, slight etching of the surface of the concrete occurred which tended to offset the darkening of the surfaces, particularly during the first six months of exposure.

Rainwater tends to cleanse concrete on which soot and grime have been deposited, and concrete is therefore usually less dirty on surfaces facing in the direction of the prevailing wind than on less exposed areas, although

the surfaces do tend to become streaky and patchy owing to the rain dripping or flowing unevenly down the surface.

## General Architectural Considerations.

Concrete is the one structural material that can be moulded at will to produce any desired shape or form of mass, or structural effect. As this Paper has shown, its surfaces can be finished in many ways. It is not sufficient, however, to limit the study of the subject to the mere consideration of the type of finish to be selected, its texture, colour, and permanence. Other important problems must be solved by the designer, including the simplicity, economy, and efficiency of design, not only of the individual elements of the structure, but also of the structure as a whole, the selection of suitable shapes and forms of mass, their disposition and inter-relation, and the proper consideration of light and shadows. Such matters are of vital importance if the structure is to have character and interest, and represent a well-balanced and harmonious entity.

Much has already been achieved by careful thought and study, and some excellent structures have been designed and erected, although a vast amount yet remains to be done in this almost limitless field of construction; but only if engineers and architects pursue the subject still farther, and only if greater care and skill is exercised by contractors and operators alike, will it be possible to make any great advance and to effect marked improvements in the design and appearance of concrete structures.

## Acknowledgements.

This Paper is presented by permission of the Director of Building Research. The Author wishes also to thank the Cement and Concrete Association for their help and collaboration in the investigation and for permission to reproduce *Figs. 12, 18,* and *22*; and Mr. W. G. Newton for permission to reproduce *Figs. 20, 21,* and *25.*

The Paper is accompanied by four sheets of diagrams and twenty-five photographs, from which the Figures in the text and the half-tone plates have been prepared.

## Discussion.

**The Author,** in introducing his Paper, said that it might perhaps seem to many that the subject of surface finishing of concrete structures was one of secondary importance at the present time. Good finishes to concrete structures were, however, just as important in war time as at any other time, since they reflected, to a very large extent, the care and efficiency exercised in controlling labour and materials during all stages of construction. Control of the quality of the work almost invariably led to economy; it was, for example, far more economical to plan the work so that when the forms were struck the exposed surfaces would present a dense and uniform appearance than it was to relax control and rely upon patching and after-treatment to conceal the blemishes of badly placed concrete.

One very important fact should always be borne in mind, namely, that surface blemishes tended to become accentuated as the concrete aged. Thus, a slightly more porous pocket of concrete which on removal of the form differed only slightly in colour and texture from the surrounding concrete would, owing to its greater porosity, not only tend to be more easily eroded on exposure to the weather but would also accumulate grime more readily on its surface; patches also became more apparent with the passage of time.

*Fig. 30* showed three successive mixes of concrete. The first was deposited quite well, and it was a well-consolidated mix; the second was probably under-sanded and poorly compacted, and the concrete had been allowed to find its own path through the formwork, with the consequence there was segregation and a honeycomb patch. No attempt had been made to obtain a really good construction joint, and the concrete had weathered badly. In one place particularly one could actually see the concrete tending to spall, probably owing to weathering in the porous layer. No attempt at serrating the surface would mask those defects.

The effect of the weathering of concrete surfaces varied considerably according to the conditions of exposure. Thus tests had shown, as would be expected, that concrete darkened more rapidly in an industrial town with a relatively high content of solids in the atmosphere than in one less polluted. In another town, owing probably to a higher acid-content in the atmosphere, slight etching of the surface of the concrete might occur, which might tend to offset the darkening of the surface. Rainwater tended to cleanse concrete on which soot and grime had been deposited, and concrete was therefore generally less dirty on surfaces facing in the direction of the prevailing wind than on less exposed areas, although the

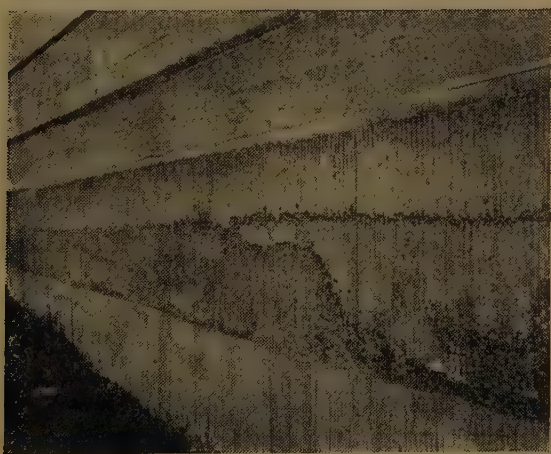
surfaces tended to become streaky and patchy owing to rain dripping or flowing unevenly down the surface.

He wished to emphasize the importance of using well-designed weatherings on all projecting features, so that rainwater was thrown clear of the walls. Probably more disfigurement to concrete surfaces resulted from lack of attention to that matter than from any other cause.

In the example shown in *Fig. 31*, rainwater had run along the sill and flowed down the surface of the wall, carrying grime with it and causing a very unsightly stain.

*Fig. 32* illustrated a very simple device, namely, a form of metal weathering which allowed the water to be collected and thrown clear of the wall. The projecting metal was placed well out from the wall, and an important feature was the turn-up at the end of the sill to prevent the water running over the end. Most of the disfigurement was caused by water running over the end of the sill.

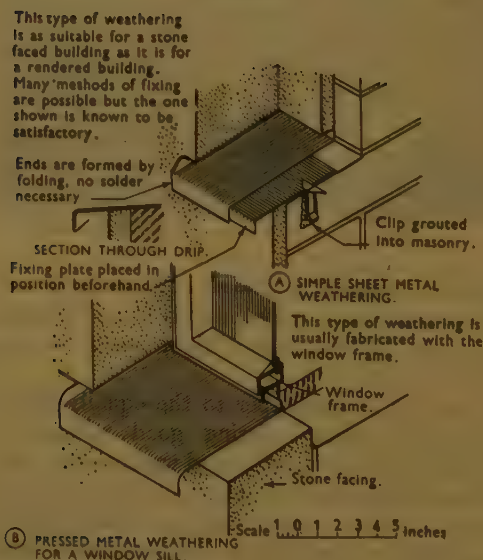
*Fig. 30.*



He had not referred in the Paper to the equally important problem of producing concrete surfaces offering good resistance to wear—for example, heavy duty floors in factories and warehouses; but judging from the many inquiries for information on the subject and from the reports of failures of wearing surfaces received at the Building Research Station, that problem appeared to merit much closer attention and study. The techniques followed in laying and surfacing concrete floors varied very considerably, and guidance was needed as to the best methods. Similarly, information was scanty on the problem of finishing the surfaces of oil-storage tanks to make them impermeable to oil.

*Fig. 31.*

*Fig. 32.*


This type of weathering is as suitable for a stone faced building as it is for a rendered building. Many methods of fixing are possible but the one shown is known to be satisfactory.
Ends are formed by folding, no solder necessary
SECTION THROUGH DRIP.
Fixing plate placed in position beforehand.
Clip grouted into masonry.
A SIMPLE SHEET METAL WEATHERING.
This type of weathering is usually fabricated with the window frame.
Window frame.
Stone facing.
Scale 1 0 1 2 3 4 5 inches
B PRESSED METAL WEATHERING FOR A WINDOW SILL.

Another and perhaps more topical subject that had not been dealt with concerned the repair of war-damaged concrete buildings. The problem of patching and re-surfacing damaged concrete was not always so simple as would appear at first sight, but further investigations were in progress.

**The President** said that The Institution had recently taken an active interest in the aesthetics of engineering structures, and the Paper formed a valuable contribution to that subject. It dealt with beauty of complexion rather than with beauty of form; in fact it might be said, in the terminology of the beauty-specialist, to deal with facial treatment, which was, of course, extremely important. It was a mere truism to say that beauty of form in a structural building or in any structure could be marred and entirely disfigured by something repulsive in the way of a complexion. In concrete buildings and other concrete structures, beauty of complexion had been in the past too often conspicuous by its absence; but the Author had given instructions for rectifying that defect.

**Mr. F. E. Wentworth-Sheilds** considered that the Paper represented an immense step forward in the endeavour to render structures more pleasing in appearance, and it went farther than that, in that it contained the essentials of what might be called good workmanship in concrete, which affected more than the appearance of the structure. For instance, the Author had given a description of the best way of making satisfactory horizontal joints, which would provide much food for thought to all engineers who erected concrete structures. They all, the dock engineer in particular, knew how difficult it was to make a really satisfactory joint when placing a new layer of concrete on top of an old one, because he found that, in erecting a quay wall, and especially a graving-dock wall, if a bad horizontal joint were made the water came weeping through that joint, causing him to weep also! The Author had suggested that the set concrete should be thoroughly roughened, the surface should be washed and saturated with water, a layer of mortar should be laid on, and finally the new concrete deposited. Usually the old-fashioned engineer, in putting up large mass concrete walls, did not do what the Author appeared to suggest should be done, namely, hack the surface all over with a pick; but he did wash the surface and brush it, and sometimes laid a layer of mortar over it. Generally speaking, satisfactory results had been obtained by that method; and it was not quite clear whether or why it should be necessary to hack the surface of the old concrete, in view of the fact that one could put down concrete in a pile-mould for instance, on a plain board surface, and obtain a perfectly good surface on the under-side of the pile. Probably the answer to the question was that a neat and watertight joint could be obtained without hacking, but that hacking ensured closer contact, and therefore a stronger joint.

**Dr. W. H. Glanville** said that he had felt at first that the Paper dealt with a subject which engineers should not think about in war time,

but perhaps it was good that they should consider the subject, because in many ways they were becoming very slipshod under war conditions, with a consequent loss of efficiency. It was very important that engineers should take the care about their structures which was essential in order to obtain the strength required. The Author had emphasized the meticulous care that should be taken in all the processes described, and that was clearly the basis of the Paper. Good quality concrete could never be obtained without care, and that applied particularly to the finish, because the worker in concrete operated more or less in a blindfold condition; he could not see the surface that was produced until the form had been struck, therefore it was very important that engineers should consider how such care was to be brought into operation. It was really a question of educating the craftsman. The people who were to construct the formwork and those who were to make the concrete had to be educated, so that they would use good quality material and understand its essential properties. Many who made concrete to-day, and had made it for many years, did not really understand the basic principles.

He had been very interested in the weathering-machine illustrated in *Fig. 2* and also in *Figs. 4* and *5*. He had found it difficult to discover a correlation between any of the results under different conditions and the results furnished by the weathering-machine, and he would like to know whether any information was available to show that the results from the weathering-machine could be correlated with practical results. The matter was closely related to the work that had been done in the Road Research Laboratory on the use of road machines to accelerate wear. It had been found extraordinarily difficult to reproduce the sort of wear that occurred in practice. All kinds of weathering devices and wear devices had been produced, but without really satisfactory results.

**Dr. David Anderson** observed that Members might be interested to know that the Paper formed part of a programme. As a result of Dr. Faber's Paper on "Aesthetics of Engineering Structures"[1], The Institution had set up a small committee to consider and report upon what action might be taken to investigate the question of surface or finish of concrete structures, with particular reference to aesthetic treatment. That committee had decided that two-fold action could be taken in spite of the war, namely, (*a*) A Paper embodying practice and research to date based upon work already done by the Building Research Station in collaboration with the Cement and Concrete Association (hence the Paper by Dr. Davey); (*b*) That the committee be empowered, as a further step, to confer with individual engineers experienced in the design of structures built of concrete, and thereafter to report whether and, if so, how far, principles relating to the aesthetic treatment of the surface of such structures might be defined.

[1] Journal Inst C.E., vol. 17 (1941–42), p. 139 (April 1941).

Dr. Anderson considered that it would be of great advantage if, when the work of the committee was completed, the results of their labours, including Dr. Davey's Paper, should be issued as a separate publication by The Institution. Further research would be needed, but that might have to wait until after the war.

He wished to make the following comments on the Paper.

*Figs.* 7, showing the darkening of concrete surfaces during exposure in London, appeared to indicate that, no matter what aggregates were used or what treatment the surface underwent, after about 3 years all came to a common value of 40 per cent. reflected light. In plain English, all became dirty. The Author had indicated numerous other defects that arose and the various ingenious methods that had been adopted to overcome them and to obtain pleasing results: but dirt still remained the enemy to concrete structures in large, dirty towns. Further research might discover means of overcoming that evil.

The Author had referred, on page 203, *ante*, to applied coverings, including glazing and metal spraying. Further research might make them more useful in the struggle against dirt.

It might be that in the long run it would be found economical and legitimate to use permanent shuttering as a finish instead of temporary shuttering for constructional purposes only. That might seem like a confession of failure, but if it resulted in structures resplendent in finishes of stainless steel, copper, or other metals, marbles (natural or artificial), plastics, or other new invented materials, engineers would be able to credit themselves with structures not only stable in themselves, such as they had long been accustomed to produce, but also pleasing to the eye and with a finish that time and weather could not affect.

Dr. Anderson could see room for vast improvements if care, forethought and imagination were applied, and he regarded the Paper as a valuable step in that direction.

**Mr. G. L. Groves** thought that if engineers, or any other body of discriminating persons, were asked to vote on the question: "Are you satisfied with the quality of finish in concrete structures in this country to-day?" an overwhelmingly large majority would answer: "No", and that majority might be even larger if the question were limited in its application to such purely utilitarian structures as retaining walls, bridge piers, and so forth, where special surface treatment, such as was described in the Paper, or the concealment of construction joints by special methods, would be out of place on economic if not on aesthetic grounds. In all structures of the kind to which he was referring it was very important to avoid the flaws and disfigurements which were a too familiar feature in work to-day; but if there was to be an improvement (and he thought the Paper pointed a way to it) he suggested, speaking in general terms, that there should be a revision of existing methods, and perhaps to some extent a change of heart.

How were engineers to take advantage of the knowledge of the improved technique described in the Paper? He suggested that, in the first place, many engineers' specifications required to be re-written and expanded, and for the amended documents he could think of no better framework than the Author's admirable Paper. To mention only one point in that connexion, the Author had drawn attention to the prime necessity of rigid control of the mix with regard to surface finish. That was a matter which had probably had far too little insistence put upon it so far as mass concrete was concerned, however meticulous engineers might have been in regard to reinforced concrete; although in their control of the latter, engineers had probably been much more concerned with quality of strength than with quality of finish.

Secondly, he would suggest that the supervision of work by the engineer's representatives required to be closer and more knowledgeable. How many resident engineers, he wondered, discussed with the contractor details of the making up of formwork, the care of formwork when out of use, the orderly disposition of construction joints, and many other points which were shown by the Author to make all the difference in the result.

Thirdly, he thought that many contractors—he might even say most contractors—should make a fresh and unprejudiced approach to several factors affecting concrete surfaces.

In all the three points that he had mentioned, however, it was for the engineer to take the initiative. He might specify perfection, but he would not obtain perfection or anything like perfection unless he had the full co-operation of those who were carrying out his instructions on the ground and the understanding co-operation of the contractor.

It might be argued by some that enhanced costs would go hand in hand with a higher standard of finish. Setting aside such shoddy workmanship as ought never to see the light of day at any price, Mr. Groves doubted whether an improvement in the results generally obtaining would cost more if the methods of carrying out the improved technique were thoroughly appreciated and properly applied. Many engineers had experience of contractors who spent a good deal of money in endeavouring to doctor a structure where bad formwork or faulty control of mixing had resulted in lipped joints and honeycombing. He had a shrewd suspicion that a number of contractors included a percentage in their price for such doctoring. That money would be very much better expended in prevention than in attempted cure. In any case, workmanship which fell short of a standard where justifiable criticism could not legitimately be offered, should not be acceptable to any engineer, and if any of the work to-day fell short of that standard it was time that an improvement in the quality of workmanship became the rule. The Author, he thought, had given very clear and practical directions for the attainment of that improvement.

**Mr. W. K. Wallace** believed that a concrete job which had a good surface was probably a job which was well done throughout. He agreed

with Mr. Groves that a better result might not, in the end, cost any more once the technique had been learned, provided the job was of sufficient magnitude to permit a reasonable repetition of the use of forms, so that a well-made form, properly designed for re-use, could be employed a reasonable number of times. Owing to the large areas available for reconstruction in some cities at the present time, there should, in the future, be larger jobs which would admit of more re-use of forms.

He would have liked to see in the Paper some more information about the absorbent form lining, which he knew was being developed rapidly in America. Further, in the United States, pre-cast concrete slabs had been used recently as formwork on exposed faces on a very large scale on war-time buildings; and he thought that was a very interesting attempt to obtain a good face. On some buildings under erection in Great Britain precast slabs were being used in that way.

The work of Mr. J. J. Earley in America was largely architectural decorative work, but the mixes which he used to obtain his excellent surfaces were very interesting. Mr. Wallace thought he was right in saying that Mr. Early used only two sizes of aggregate; that was absolutely contrary to the ideal of graded aggregate which engineers in Great Britain were normally brought up to consider the proper thing. The walls of Meridian Park, Washington, D.C., had been up for a considerable number of years and the surface was still quite attractive. Mr. Wallace was aware that the atmosphere of London was much dirtier than that of Washington, but if the walls of that park had been built in Great Britain they would have formed a very much better job than much of the work that was seen there. One of the chief troubles in Great Britain was that insufficient attention was devoted to lining the forms. Often on going to look at a job one was told: "It is all right, except for that little bit at the far end"; and it was that little bit at the far end that one always saw afterwards. One hesitated a long time before ordering a contractor to take down set concrete and put it up again, because, although the new work might be better aligned, a nasty joint would occur between the new work and the old. The consequence was that a good deal of unsatisfactory work went through.

With regard to roughening the upper surface of a lift of concrete, he agreed with the Author; but he would like to ask whether there was any objection to roughening the top of a lift of concrete shortly after it had begun to set, but before it had become hard, in other words, when it was a job for a stiff brush or a steel brush rather than for a pick.

There was only one point which he wished to criticize in the Paper, and that was very small. The Author had shown a recessed joint in a vertical surface with the break half-way up the joint. Mr. Wallace thought that it would have been better to make it farther up, so that the junction between the two lifts was masked by the shadow of the recess.

**Mr. R. Carpmael** said that he wished to emphasize the importance of

correct forms and good workmanship. He had first made the acquaintance of mass and precast concrete at Fishguard, under Mr. G. Lambert Gibson, M. Inst. C.E., and had been taught to regard it as an axiom that if surfaces required retouching after the moulds had been released the work had been badly done. The best example of finish of concrete using natural stone in the aggregate was, in his experience, at Fishguard harbour, where, as it was desired to carry out a colour scheme for the station buildings, certain slabs were required to be chocolate coloured and others light yellow. Some tunnels in Devonshire were then being opened up, and Mr. Gibson, who at that time was also in charge of work at Plymouth, thought that the Dawlish rock which was being obtained would be very suitable for the darker slabs, and it was so used. The upper slabs were coloured with pigment (ochre). These slabs had stood for 38 years, and, although he had not seen them lately, he was quite sure that they were as good now as when they were erected. It was true that they were under a glass roof, but they were exposed to the action of salt air and often salt spray. The coping stones of the quay wall at Fishguard were of precast concrete made of the local natural stone—a very hard igneous rock; after the blocks were released from the moulds the top surfaces and the faces were rubbed down with brick, in order to remove the laitance and expose the chippings. Those copings had been in existence for the same period as the station buildings, and had been subjected to the customary hard wear of quay walls in constant use for shipping.

One of the most unsatisfactory features in the use of precast concrete blocks for house building and wall building was the terribly drab uniformity of the pattern. It was true that there might be three or four patterns, A, B, C and D (if as many), but that was about the extent of the variation, and a house or wall built of blocks of even those few stock patterns was almost intolerably monotonous. A much better effect would be obtained if the blocks, before they were perfectly hard, were cleaved along prearranged lines, leaving a draft margin, so that half the surfaces were slightly convex and the others slightly concave. In that way a much greater variation of pattern could be obtained. That method had been used, with very pleasing effects, for a Great Western Railway viaduct at Newquay, and on the new electric line from Acton to Ruislip.

The Author had referred to the question of the accentuation of joints by projecting V-shaped joints. An alternative method was to recess the "V"; that lightened the effect, and if there were any inequalities, due perhaps to bad workmanship, they would not be so evident. Such joints had been used on several Great Western Railway structures.

He was interested in the Author's brief reference to glazed or polished concrete. That process, after extensive experimental work, had been successfully employed by the Great Western Railway on urinal stalls and had proved to provide a sanitary and economical substitute for glazed earthenware.

**Mr. P. G. Bowie** felt that to some extent the outstanding feature of the Paper was the emphasis which the Author had laid upon craftmanship —the actual making and placing of the concrete—that was, the operatives' work. Bearing that in mind, it seemed to him that it might be advisable to stimulate the training of operatives by the formation of a definite trade of "concreter," because a man who was a tradesman, such as a bricklayer, had a definite interest in turning out a good job, and would take particular care that such accidents as the Author had indicated, at joints and other places, should not happen. No resident engineer could be in several places at once, but with well-trained men who were keen on their work, many of the abuses of concrete, as they had been called, would not arise.

**Mr. W. G. Newton** said that he felt rather like Daniel, because he was a representative of the architectural profession. Reference had been made in the Paper to certain structures with which he had been fortunate enough to be associated, and he was very glad to attend the meeting, because he felt that the more engineers and architects could see eye to eye and march shoulder to shoulder the more progress they would make and the more weight they would carry.

He was surprised that none of the speakers in the discussion had referred to the little devil, that was, the laitance or cream that developed on the outside of the concrete, which after 3 years was grey, and after 5 years was a black cobweb over the whole structure. Many structures which looked beautiful in their virgin days, shining and bright, 5 years later looked like old discarded landladies with cobwebs in their hair.

The method adopted at the Marlborough College laboratories was to chamfer the edges of alternate 6-inch boards, so that at every 12 inches there was a line running through, and directly the formwork was taken down the concrete was brushed with a stiff brush, which removed nearly all of the treacherous cream, so that very little was left to look unsightly afterwards. Probably the experience of others was similar to his own, namely, that one could not really say how difficult it was going to be to get all the laitance off. If the work was being done in soft rainy weather it could be removed fairly easily, but on a hot summer day the removal was much more difficult. He considered that without such removal the finish could never be regarded as satisfactory, because of its unsightly appearance after a few years.

The making of lines across the surface of concrete was simply a method of distracting attention from the lifts. Concrete could be treated as the Americans and the Swiss very often treated it, namely, it could be bush-hammered, but Mr. Newton regarded that as the wrong way of treating a material like concrete. It produced a broad-cloth effect instead of a Harris tweed effect, whilst in his opinion, concrete was like Harris tweed, an easy-going kind of material which should be treated in an easy-going way. Little lines on it and little chips here and there were in keeping with the Harris tweed nature of concrete, and the less it was "fussed over"

the better. There was no doubt that, so far as its exterior appearance was concerned, concrete was a very unforgiving material. If anything went wrong, it could never be righted.

He felt it an honour to be allowed to address the meeting, and he thought it was very desirable that whenever possible engineers and architects should discuss together such problems as those with which the Author had dealt.

**Mr. Alister MacDonald** considered that the Paper presented not necessarily a new idea of concrete, but another picture of it as something which was very human after all. The Author had described it as the most abused of materials, and he was obviously right. It was fascinating to think that if one did anything wrong in concrete it would never forgive one, and thanks were due to the Author for showing how initial mistakes could be avoided.

Mr. MacDonald thought that the point which had been made about the importance of co-operation by the operatives should be stressed. Mr. Bowie had suggested that operatives should be taught more, and Mr. MacDonald considered that they should be given the Author's Paper to read. He had derived considerable amusement from endeavouring to obtain good surface finishes to concrete by discussing the subject with operatives and with builders, sitting down on the job and making little samples, and apart from standard practice, using all kinds of things to try to get a good effect. Technical education in the building industry after the war would be strengthened by architects (he put them first because he was an architect himself), engineers, and operatives all studying together such Papers as the Author's. They would then put up much better buildings and be doing their combined part to make the community a better place in which to live.

A very important point had been raised by the Author in connexion with formwork, and the setting out of constructional lines to decide beforehand where the lifts were going to show and where they should be, and another very important point to which reference had been made in the Paper was that it might be necessary to re-mix some of the concrete nearer the actual seat of operations. Architects would often like to have concrete re-mixed nearer the seat of operations, but they dared not suggest it because an extra would be involved which would have to be explained to the client, or the builder would have to cover up that extra by doing some inferior work somewhere else. Therefore, he would like to emphasize the Author's contention that the whole of the work should be planned beforehand, should be shown on drawings in the same way as joinery details were shown, and should be described in so much detail that the builder would know every process and every cost of mixing, at whatever part of the job the work might be required. Then the job would be priced properly, and architects and engineers could exert their authority to see that it was carried out properly.

He had read with horror the suggestion of squirting metal on to concrete, and he hoped that that would not be encouraged. Surely it would bottle up the natural drying-out process which should take place, and he wondered how far that might affect the ultimate value of the structure. To a smaller degree the same thought went through his mind when he read about staining by chemical reaction. That was a very interesting line, and he hoped that more would be heard about it; but, again, if chemicals were used to get certain reactions, how far would that interfere with the ultimate quality of the concrete?

He would like to echo what Mr. Newton had said with regard to cooperation. Architects and engineers must work much more closely together, and he ventured to suggest that the architect could help the engineer on the aesthetic side of the subject, whilst the engineer could help the architect in the design of the weight-bearing part of the structure. Those were old questions, but they were questions which so far had been discussed underground, and he felt that Papers such as the Author's brought them very much to the surface. He hoped that one result of the Paper would be that engineers and architects would be able to discover common grounds of discussion, so that not only would they put their own professions into proper and efficient working order, but also by working conjointly they would do a work of real value to the community as a whole and put up buildings that used materials properly and rationally.

**Sir Leopold Savile,** referring to the question raised by Mr. Wentworth-Sheilds with regard to making a good horizontal joint, quoted the Author as stating that after the surface of the set concrete had been picked over and washed a layer of mortar should be spread over it before pouring the new lift of concrete. Some years ago Sir Leopold had found, when taking down a dock wall made of very good concrete, that when he reached construction joints the concrete separated and came away at those joints quite easily. He was subsequently informed by the late Mr. Felkin, the contractor's engineer in charge of that work, that those joints had been made exactly in the manner recommended by the Author and a layer of mortar had been laid on the old concrete before depositing the new. When Sir Leopold remarked that, "In spite of that it came away," Mr. Felkin replied: "On account of that, in my opinion, it came away." Sir Leopold inquired whether that point had been considered and practical experience gained in regard to the effect of the mortar, as his own experience confirmed what Mr. Felkin had implied.

*** **Dr. E. Probst** observed that, generally speaking, the provision of a surface finish depended upon the nature of the structure. A warehouse would require a finish different from that of a factory, for aesthetic as well as for practical reasons. The surface treatment of bridges of plain or reinforced concrete might be different from those and from mass concrete

*** This and the following contributions were received in writing.

work, such as high dams or other hydraulic structures. The investigations of the U.S. Cement Association at Chicago, a few years ago, on high dams throughout the country, proved that for many years the value of a special membrane or any other kind of special surface treatment had been overestimated, whilst the importance of the densest possible concrete body of the structure had been underestimated.

The influence of expansion joints in all kind of concrete and reinforced-concrete structures upon the surface treatment was evident, because it affected possible cracking. It should be borne in mind that any structural movement was followed by a movement in the surface coating. Any discontinuity in the core was followed instantly by that of the coating. Any rusting of reinforcing-bars caused staining in the surface finish similar to that illustrated in *Fig. 8*, facing p. 190, *ante*.

Moreover, the method of making, depositing, and controlling the concrete construction would affect the type of surface treatment to be chosen.

The foregoing showed that various factors of design and construction, as well as individual and local conditions, in addition to aesthetic reasons, affected the surface finishing. Generalization or schematization should therefore be avoided.

The questions of board-marked textures, and of smooth or rough surfaces, as shown in *Figs. 18–26*, had been widely discussed in Europe and, even more, in the United States, during the years between the two wars. The ideal structure would have a surface finish with no coating at all, and a treatment adapted to the design of the structure. The Author had rightly emphasized the importance of producing a good concrete material, whatever subsequent treatment of the surface was to be adopted. At the same time special attention should be devoted to the design of an unexceptionable formwork.

The Author's recommendation that the mixing-plant should be installed as near as possible to the point where the concrete was being deposited did not apply to ready-mixed concrete, as successfully used in the construction of the 595-foot-span arched Tranebergssund bridge at Stockholm (built in 1935), shown in *Fig. 18*. The main feature of that work, besides an excellent formwork, was a far-reaching control of the concrete-making in a factory not very near to the construction-yard. The concrete, transported in special watertight trucks with agitators, had to be deposited not later than 1 to 2 hours after mixing.

The Author had advocated that the designing engineer should consider very carefully where the contractor was likely to make construction joints, and that he should indicate at elevations the exact positions of those joints throughout. Whilst Dr. Probst agreed that the designer should specify very closely the surface treatment to be employed, he was rather doubtful whether a useful purpose would be served by asking the contractor to observe the exact position of such joint, because it was not always

possible to indicate in advance where the concreting was to be interrupted. Much depended upon weather conditions, so essential to the progress of the construction. If the desired co-operation existed between engineer, architect, and contractor, it would not be necessary to fix the construction joints in the drawings, and experience had proved that no difficulty was found in producing such joints as strong as they ought to be. On the other hand, details of shuttering and formwork, as well as the method of finishing concrete structures, could and should be decided upon before construction was started.

**Dr. W. L. Lowe-Brown** observed that several speakers had referred to the Author's suggestions for securing good horizontal joints, namely :—

(1) roughening the surface of the old concrete ;
(2) cleaning and wetting ;
(3) applying a layer of mortar to the wetted surface before beginning to place concrete.

The necessity for the first depended upon the nature of the surface on which the new lift was to be laid. If the previous lift had been deposited wet, and if the interval between lifts had been long enough for the laitance to have become quite hard, roughening in addition to a key was very important. Dr. Lowe-Brown did not question the advantage of the second step. The need for a layer of mortar depended upon the wetness of the mix. He considered that with a good dry mix it was definitely beneficial to use mortar. His opinion was based upon the following experience, in constructing a tunnel lined with mass concrete with wall approximately 20 inches thick and a mixture of 1 : 3 : 5 made with crushed granite aggregate to pass a 2-inch ring, and kept rather dry. The invert was placed first, leaving a horizontal joint at the base of the curved side-wall. There was usually an interval of a week or more before placing the side-wall. The concrete of the side-walls was well worked and the resulting face was first-class. After the forms had been removed leakage occurred at many points along the joint between the invert and the side-walls where the tunnel was below ground-water level. To stop that leakage the concrete was cut away and replaced by a stronger mixture. At every point where that joint was exposed, it was found that the concrete at the face, which had been thoroughly worked to get a good surface, was quite dense, but the back portion for a depth of 3 inches or more was almost invariably slightly honeycombed. Since then he had noticed similar honeycombing at the joints wherever concrete walls had been cut away and a section of a joint exposed. That led to the conclusion that it was much more difficult to work the concrete properly at the bottom of a lift where the tools used for that purpose came in contact with the hard surface of the previous layer than higher up where the coarse aggregate could be worked into the quaking mass. To overcome that difficulty Dr. Lowe-Brown always specified a layer of 3 inches of comparatively soft mortar at the bottom of each lift,

so that the coarse aggregate above could be worked into it and so start the mass quaking and produce conditions similar to those which would automatically occur higher up in the lift.

**Mr. E. E. Morgan** observed that when a Paper giving particulars of the results of scientific research was submitted, the first thing the practical engineer did was to see whether, and to what extent, the results presented were capable of direct application under modern conditions of engineering practice.

Whilst the Paper contained much information of exceptional practical value, the Author had omitted to give any information on one very important point, namely, the workability of the concrete. Could he say what degree of workability was used, preferably in terms of the compacting factor, since that appeared to be the only suitable standard that could be used as a measurement of workability? Would he also state which water/cement ratios were found to be satisfactory for any tests that might have been carried out on the more common aggregates, such as granite and gravel, and what were the maximum sizes used? Were the variations in the gradings of the fine aggregate referred to on page 185, *ante*, those that were common in the natural sands?

It was reasonable to infer that for most works it was the Author's intention that the concrete which was used against the shuttering would also be used in the main structural members. With modern conditions of control to produce within close practical limits a mix having a specified water/cement ratio, it should be possible to design the mix so that not only should it have the required specified minimum strength, but also that its workability should be the most suitable for obtaining a satisfactory surface without risk of honeycombing or segregation. As the test-pieces were compacted by vibration, it would be necessary to use vibratory methods in the structure itself for the same workability. Even if that were not possible, the workability could be adjusted to allow for hand-compaction, using the Author's figures as a guide. Could he recommend a suitable degree of workability in terms of the compacting factor for concrete surfaces where compaction was carried out by hand?

On page 191, *ante*, the Author had stated that "the slump of the mix to be used for the various portions of the work should be clearly stated in the original specification." Remembering the extreme difficulty of controlling the water-content of the concrete by means of the slump test and the fact that a 1 : 2 : 4 mix by weight, having a water/cement ratio of 0·62, might produce slumps ranging from about 1 inch to 6 inches, or even more, according to the nature of the slump—Mr. Morgan's information was confirmed by a publication issued by the Department of Scientific and Industrial Research—was the Author confident that any very satisfactory results would be obtained by that method of control?

Mr. Morgan suggested that although the compacting factor apparatus was not yet available as a yardstick for measuring workability, the Author

would be quite justified at the present time in recommending that the required degree of workability should be regulated by proportioning the mixes by weight, adjusting them as required to compensate for the water in the form of moisture which was included in the weight of the aggregates and working to a definite water/cement ratio. That method had been carried out with complete success on road and other works by the Surrey County Council for several years with little, if any, additional cost.

**Mr. H. E. Steinberg** observed that the subject had been thoroughly investigated during the past 25 years, and it was a tribute to the Author that he had found something novel and stimulating to say about it.

In order to obtain a tolerable surface finish straight from the shuttering, it was essential to have vertical stopping-off boards against which the concrete could be properly punned. Work such as was shown in *Fig. 30* should never be tolerated, and it was difficult to understand how, in that case, such a large area of wall could have been done without someone in authority changing the contractor's methods.

Vertical joints could be easily dealt with by stopping-off boards, and became almost invisible, but horizontal joints were more troublesome. The suggestion to stop the concrete temporarily behind small taper battens, as illustrated in the Paper, had emanated from Mr. Steinberg's office about 15 years ago, and had been widely and successfully adopted. He suggested, however, that it was not practicable to fix in advance the positions of stopping-off points on work of any size, as that depended upon the type of plant installed by the contractor, the number of men employed, the length of the working day, and the caprice of the weather.

The references to the Twickenham bridge, in the design of which his Company had collaborated with Mr. Maxwell Ayrton, were interesting, but there were several other different types of surface finishing on that bridge from which useful lessons could be learnt. One of the most satisfactory surfaces had been obtained by the use of uncrushed flint aggregate of small size, from which the surface cement had been rubbed away with rough canvas and water before thoroughly set. The resulting concrete was smooth to the touch, as well as pleasing in appearance. The bridge had been in existence about 12 years, and no unsightly defects had developed. The soffits of the arches were cast on ply-wood shuttering, and subsequently lightly bush-hammered. There was no patching.

Chiswick bridge was done at the same time, in collaboration with Sir Herbert Baker, A.R.A., but in that case most of the visible surfaces were faced with Portland stone. The soffits of the arches were also cast on ply-wood and bush-hammered after removal of the shuttering. The workmanship was not so good as at Twickenham, but nevertheless the result was above the average.

Mr. Steinberg agreed with Sir Leopold Savile that it was inadvisable to grout the horizontal surfaces, where concreting had been temporarily stopped. Usually it was not practicable to rake the concrete at those

points, owing to the quantity of reinforcement, and to the fact that the shuttering to the back and front surfaces was usually in position.

**The Author**, in reply, expressed his thanks for the very kind reception which had been given to his Paper. He considered that the main purpose of roughening horizontal joints was to remove the laitance film, which, if left on the concrete, prevented a good bond to the new work. Removal of laitance scum was obviously desirable; it could be removed soon after deposition of the concrete, that was after the initial hardening—the next day or the day after—by wire-brushing. The operation also served to expose the new aggregate and so obtain a better bond. If the concrete was very hard, wire-brushing would probably not be sufficient and resort to bush-hammering or scarifying would be necessary.

He agreed that the use of too much mortar might be detrimental in causing a shrinkage crack to develop in the rich mortar layer. With leaner mixes for mass work it was important to put in a thin layer of mortar. Mixes of 1 : 1½ : 3, or richer, were already fairly heavily loaded with mortar, and probably the extra mortar against the joints was not so important.

He had dealt with the subject elsewhere [1], and the conclusions arrived at were, briefly, that if the concrete had been placed for more than 4 hours, but not longer than 3 days, the surface should be cleaned and the laitance film removed by wire-brushing and by thorough washing with clean water; it was inadvisable to disturb the surface of such concrete by bush-hammering or scarifying unless the concrete had become exceptionally hard. A layer of cement mortar of similar composition to that embodied in the new concrete should then be applied to the prepared surface and should be followed at once by the new concrete, which must be well tamped into position. If the concrete were more than 3 days old its hard surface should be roughened and cleaned by bush-hammering and wire-brushing and thoroughly washed to remove all loose particles; a slurry of neat cement should then be brushed upon the prepared surface and well worked in; a layer of cement mortar of similar composition to that embodied in the new concrete should then be applied before the slurry dried and should be followed immediately by the new concrete, well tamped towards the joint.

The results produced by the artificial weathering machine were purely arbitrary, and could not pretend to reproduce the conditions on any one or more sites, but it had been found that they corresponded fairly closely with the conditions in an industrial town, which happened to have a fairly heavily polluted atmosphere. He did not consider that the weathering-machine could be used for ascertaining how a particular concrete specimen

[1] "Construction Joints in Concrete", Building Research Special Report No. 16, 1930; "Bonding New Concrete to Old", Building Research Bulletin No. 9, 1930.

would weather, for example, in Birmingham or Leeds or Sheffield, because the degree of weathering would vary with the pollution of the atmosphere. The weathering-machine was useful, however, in helping one to say whether one mix with a particular type of aggregate was likely to stand up better than another; it was therefore a method of pre-selection.

Dr. Anderson had referred to concrete becoming dirty and to the indications in *Fig. 7* that all the concrete showed a common level of dirtiness after a few years. That was quite true, but the point which was not brought out in the curves was that some concrete, although it became dirty, did so uniformly. For instance, it had been found that whilst a bush-hammered granite concrete became very dirty its appearance was not objectionable, because it weathered uniformly. That made a considerable difference; slight griminess did not matter so long as the concrete maintained a uniform appearance; it was streakiness or patchiness in the concrete which was objectionable.

He was sorry that he was unable to give Mr. Wallace much more information about absorbent linings for concrete shutters than was contained in the Paper, which had been prepared a few months previously. That development was in an experimental stage. Just recently, however, he had seen in an American journal an advertisement of absorbent linings for shutters, and he assumed that the linings had now come on to the market; they were very similar to absorbent wallboard. He had carried out a few tests at the Building Research Station, and had found that absorbent lining certainly produced a very fine mat surface for concrete and prevented the formation of the objectionable laitance.

With regard to the position of the break in *Fig. 13*, he agreed with Mr. Wallace that that should be as near the top of the recessed joint as possible.

In reply to Mr. Morgan the water-content of the 1 : 2 : 4 concrete with different types of aggregate used for the series of tests described in the Paper was as follows :—

| | |
|---|---|
| Portland stone aggregate | 0·90 (by weight of cement). |
| York stone | 0·90 |
| Welsh granite | 0·60 |
| White marble | 0·60 |
| River gravel | 0·60 |

The slump varied between 1 inch and 2 inches. The coarse aggregate was graded to give 66·7 per cent. by weight between $\frac{3}{8}$ inch and $\frac{1}{2}$ inch and 33·3 per cent. between $\frac{3}{16}$ inch and $\frac{3}{8}$ inch. The fine aggregate contained equal proportions by weight of material between the following sizes :— No. 7 sieve to $\frac{3}{16}$ inch, No. 14 to No. 7; No. 25 to No. 14; No. 52 to No. 25; and No. 100 to No. 52. The straight-line grading of the fine material might be taken as a fair average between naturally occurring sand and stone artificially crushed. Generally, natural sands would contain a

rather higher proportion of material below No. 25 sieve, whereas those artificially crushed might be expected to contain a lower proportion.

With regard to the degree of workability in terms of the compacting factor which should be used where compaction was to be carried out by hand, the Author considered that the compacting factor should not be less than 0·92. Whereas he agreed with Mr. Morgan that the compacting-factor test developed at the Building Research Station was possibly a more scientifically accurate method of judging the workability of a concrete mix, particularly if changes in the grading of the aggregate were likely to occur, he regretted that the slump test had not been more frequently used in Great Britain. He felt certain that, despite its limitations, much of the poor work that had been carried out might have been avoided by its use. It was probably correct to say that no other single test had contributed more to the production of good concrete than the slump test; in America, particularly, it was still regarded as a reliable measure of the relative water-content of mixes, but only within certain limits of concrete workability and provided other variables, such as batch weights, grading of the aggregate, and temperature of the mix remained practically uniform.

He also agreed that to obtain the best results materials should be proportioned by weight. It had always been the practice to do that at the Building Research Station, and every endeavour had been made to encourage others to do so.

He did not think that Mr. MacDonald need be afraid that metal spraying would ever be used for large surfaces. It was expensive, and it had been used only for decorative relief.

He wished particularly to thank Mr. Newton and Mr. MacDonald for the kind remarks which they had made as architects.

Paper No. 5280.

# "The Incidence of Drought in Queensland during the 50-year Period, 1886–1935."

By William Ralph Baldwin-Wiseman, M.Sc., M.Sc. (Eng.), Assoc. M. Inst. C.E.

*(Ordered by the Council to be published in abstract form.)*[1]

Investigation of the incidence of drought is usually hampered by the imprecise nature of the available records concerning (1) its time of onset and its duration; (2) the month-to-month variation in intensity; (3) the regional extent; (4) the duration and the meteorological characteristics of the intervals between periods of drought. These defects are more evident in early records because drought, being negative in its characteristics, has not been reported in such detail as floods; but since the middle of the last century more complete meteorological, hydrometrical, and ancillary data—such as stock and crop returns—have been compiled, affording a reliable basis for the formulation of protective schemes.

The term "drought", as used throughout the Paper, implies that in any continuous period of three or more months the cumulative rainfall at the end of each month is 50 per cent. or more lower than the corresponding mean monthly rainfalls of the same period recorded over a period sufficiently long to give reliable results. If such extended records are not available, then, as in the case of Queensland, the mean taken is that for the whole period of rainfall records at each station. The data thus obtained can be utilized to compile charts of "isodefs", or lines of equal percentage deficiency from the mean, which provide a month-to-month review of the extent of the drought area, the boundary of which is the 50-per cent. isodef, and indicate the variation in the intensity of drought throughout the drought area. Such charts, however, whilst furnishing very precise data, entail considerable labour in a recurrent drought region, and another type, the "isoagdef chart", is preferable for such regions. This is prepared in a similar manner, but the basic data, for each station, are the aggregates of all the monthly deficiencies at that station during the period of review. Examples of such charts are given in the Paper.

The Author's study utilizes the monthly rainfall records available from sixty well-distributed stations, which were complete for the whole 50-year period of review, from twenty other stations deficient in respect of only a few months, and from a further eighty stations with less complete records. Although the number is small for the area of 670,000 square miles occupied

[1] A limited number of stencilled copies of the full Paper are available.—Sec. Inst. C.E.

by the State of Queensland, it represents practically the maximum available for the investigation, since reliable records have been available only since 1888. The incidence and nature of the rainfall in Queensland over the 50-year period are reviewed in detail, and the drought data, derived from the rainfall statistics, are tabulated and discussed; these show the varying incidence of drought along the east coast and the Gulf coast, and the more frequent recurrence and severity in the more remote inland areas.

The Author considers that a close systematic analysis of long-term meteorological records on the lines indicated will afford

(1) valuable data for the investigation of the water resources of catchment areas and underground storages;

(2) a drought index of pastoral and agricultural lands, in arid or semi-arid regions for

(a) use in connexion with insurance against drought; the danger of utilizing only short-term records is clearly demonstrated by the comparison of drought values in various decades;

(b) use by valuers advising as to the acquisition or leasing of pastoral lands, or by financial institutions considering loans on stock or holdings;

(c) use by officials reviewing applications for relief in respect of rent, rates, or other charges, drafting schemes for the accumulation of funds in good years to meet occupational obligations in lean years, or reporting as to the classification, rehabilitation, or abandonment of marginal lands.

The Paper is accompanied by five Tables and eight sheets of diagrams.

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## INGENUITY COMPETITION, 1941.

# "Sealing a Cofferdam."

By Geoffrey Winston Roberts, Assoc. M. Inst. C.E.

In connexion with the construction of a cofferdam, using steel sheet-piling and timber framing, the site and extent of the dam were strictly limited by an existing timber wharf, the upper portion of which had to be dismantled, whilst the material to be penetrated by the piles consisted of large limestone pitching blocks, which were, so far as possible, removed before the piles were driven; up to 12 feet thickness of tipped stone ranging from quarry spalls to large boulders; and mud and conglomerate of unknown depth: later this was found to be as much as 60 feet in places.

It was found that the sheet-piles pushed boulders down in front of them through the mud, thus breaking the cohesion which could normally be relied upon to form a seal and allowing continual "blows" of water down under piles into the dam when it was pumped out.

The layer of tipped stone was very solid, having been subject to tidal action and mud deposit for many years, but was yet sufficiently porous for water to travel through it virtually unimpeded. Thus no indication was given on the outside of the dam as to where the "blows" were taking place, and methods of forming a seal by placing clay on the outside of piles were useless. Similar circumstances occurring inside the dam precluded the adoption of quick-setting plugs of concrete, as the water would simply have found its way elsewhere through the stone.

A temporary seal was effected time after time by re-driving the sheet-piling to get a little more penetration, but there was a limit to this and the trouble recurred in one place or another. As might be anticipated in the circumstances, increased pumping capacity merely increased the inflow.

The Author proposed to force grout down inside the dam to the seat of the trouble, using such plant as was already on site. Actually this was found very effective in forming a temporary seal while the bulk of the stone was excavated, and from the experience obtained a rapid method of dealing with subsequent "blows" and obtaining a proper seal was developed.

The scheme, as finally worked and found most effective, was as follows:—

Two lengths of 65-lb. crane-rails were fish-plated together to form a unit about 60 feet long, which was lifted by a Scotch derrick crane and lowered inside the dam near to where the "blow" was believed to be. Rough guides were fitted to maintain the rails vertical, and then the McKiernan-Terry hammer was picked up by the derrick and lowered on to the end of the rails, the steam was turned on, and the rails were driven into the ground.

Driving was fairly slow through the layer of stone and then, on encountering the mud, the rails would go down easily, but if the position of the "blow" had been located the rails would run down under their own weight once the stone had been penetrated. One or two trials made the men adept at rigging up the plant and judging whether the seat of the trouble had been located, and the actual location of the trouble formed, in the circumstances encountered, one of the main difficulties.

Once a soft spot had been located, the hammer was removed, the rails were carefully withdrawn, and lengths of 2-inch diameter steam-pipe coupled together were lowered down through the guides used in driving the rails so as to find the same hole through the stone.

The pipes were worked down well below the level to which the excavation had to be taken or, if they ran freely, they were allowed to go as far as possible and were then lifted slightly.

Water was connected to the top of the pipes to wash out and make sure that the lower end was clear. If the water could not flow away the pipes were worked up and down until they cleared and then worked downwards for as far as it was possible to keep them clear.

Rich cement and sand grout (about 1 : 1), using fine sand, was next mixed and fed down the pipe. It had been anticipated that the mud might settle back solid and compressed air be required to force the grout down, but in actual practice it was found that if the grout was rich in cement it flowed freely and a sufficient head was obtained by simply feeding into the top of the pipe, which might be anything from 5 feet to 20 feet above water-level, depending upon the state of the tide. This grouting was continued for as long as the pipes would clear themselves, the pipes being slightly raised as the process was continued until the lower end was just below formation-level.

After such a hole had been grouted up, and as a precaution, a further hole was made on either side of the first, to ascertain whether further grout could be injected, but this was found not to be essential and after allowing 36 hours for setting, the dam was once more pumped out.

The success of this method was demonstrated by the fact that whilst, as previously mentioned, in the case of re-driven sheet-piles the trouble might recur at the same spot, when this grouting was carried out there was no recurrence of the trouble and the weak spots were thus finally eliminated as they appeared.

Probably 7 tons of cement was used in all, a large proportion of which was on one major "blow." An alternative proposal, had this scheme failed, was to force down grout under pressure to try to form a plug over the whole base of the dam below formation-level; but had that proved possible, it would probably have needed ten times the material for the dam in question, whilst for a larger dam in similar circumstances a tremendous expense might be involved.

This process of first locating the trouble by driving rails which are easily handled and extracted, and then simply running in grout to the seat of the trouble, forms a ready method of sealing, using only gear which is normally available on work of this type.

The dam was constructed for the erection of screening-chambers in connexion with the Plymouth Corporation Electricity-Supply, under Mr. J. Paton Watson, M. Inst. C.E., City Engineer and Surveyor.

# OBITUARY.

FIELD-MARSHAL H.R.H. PRINCE ARTHUR, FIRST DUKE OF CONNAUGHT AND STRATHEARN, K.G., P.C., G.M.B., G.C.S.I., G.C.M.G., G.C.I.E., G.C.V.O., the third son of Queen Victoria, was born on the 1st May 1850, and died at Bagshot Park, Surrey, on the 16th January 1942. He was educated at the Royal Military Academy, Woolwich, and in 1868 was appointed Lieutenant in the Corps of Royal Engineers. During his long military career he saw active service in many parts of the world, and his life was largely devoted to the Army.

He was elected an Honorary Member of The Institution at a Meeting held on the 7th May 1872; and graciously attended in person to unveil the Roll of Honour in the Institution building on the 27th October 1922.

SIR ROBERT ELLIOTT-COOPER, K.C.B., V.D., was born at Leeds on the 29th January 1845, and died at Knapwood House, Knapwood, Surrey, on the 16th February 1942. He was educated at Leeds Grammar School, and commenced his engineering pupilage with the late Mr. John Fraser, M. Inst. C.E., in 1864, under whom he served as resident engineer on the construction of railways in Yorkshire until November 1874, when he travelled to India to inspect engineering works. He returned in May 1875, and in June 1876 commenced private practice in Westminster. During his long career he was responsible for the design and construction of numerous railway and other engineering works in many parts of the world, and he travelled extensively in connexion with his professional work. He acted as Consulting Engineer to the Regents Canal and Dock Company, and also from 1908 to 1916 for railways in Nigeria and the Gold Coast Colonies, whilst he was in frequent request as an arbitrator in railway matters. In 1900 he was gazetted Lieutenant-Colonel of the Engineer and Railway Staff Corps, of which he bcame Colonel-Commandant. During the war of 1914–1918, he acted as Chairman of the War Office Committee of The Institution. In 1919 his services were recognized by his creation as K.C.B. From 1911 to 1928 he was Chairman of the Committee of the Engineering Standards Association on Steel Bridges; in 1912 he was appointed a member of the Advisory Board of the Science Museum, and in 1914 a member of the India Office Committee for appointments in the Public Works Department and the State Railways; of the General Board of the National Physical Laboratory; and of the London County Council Tribunal of Appeal (Building Act). From 1916 he served on the Committee on the Deterioration of Structures exposed to Sea Action; and in 1919 was appointed a member of the Government Mining Sub-Committee. In 1925 he was appointed Technical Adviser to the Treasury to supervise payments to contractors under the Trades Facilities Act.

Sir Robert was elected an Associate Member of The Institution on the 3rd May 1870, and was transferred to the class of Member on the 11th January 1876. At the Engineering Conference held in May 1897, he presented a Note on "The Location and Cost of Working of Pioneer Railways"[1], and at the Conference of June 1899, read a Note on "Causes of Earth Slips in the Slopes of Cuttings and Embankments of Railways, and how to Prevent or Remedy them."[2] He was elected a Member of Council in 1900 and a Vice-President in 1909, and became President in November 1912, in which capacity he occupied the Chair at the first meeting in the new building in October 1913, having previously acted as Chairman of the Building Committee after the death of Sir William White in February 1913. He was elected an Honorary Member of The Institution on the 22nd February 1938.

In 1878 he married Fanny, daughter of William Leetham, of Hull, and had three sons and three daughters. One of his sons, Lieutenant-Colonel N. B. Elliott-Cooper, V.C., D.S.O., M.C., died in a German hospital as a prisoner of war in February 1918.

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[1] Min. Proc. Inst. C.E., vol. cxxx (Session 1896–97, Part iv), p. 178.
[2] Min. Proc. Inst. C.E., vol. cxxxviii (Session 1898–99, Part iv), p. 383.

## CORRIGENDUM.

February 1942 Journal. Page 294, column 2, line 6. *For* "Broadberry" *read* "Broadbery."

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NOTE.—*Pages [1] to [23] can be omitted when the Journal is bound in volume form.*

# NOTICES

## No. 6, 1941—42

## APRIL, 1942

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## MEETINGS, SESSION 1941—42.

### ORDINARY MEETING.

The following Paper will be discussed on the date shown :—

1942.

May 12 (Tues.).† (5.30 p.m.) " **Treatment of Water for Domestic and Industrial Requirements—Some Problems and Methods,**" by Albert Parker, D.Sc.

### ROAD ENGINEERING SECTION.

Apr. 21 (Tues.).† (5.30 p.m.) Paper for discussion: "**The Effects of Modern Road Layout on Bridge Design,**" by C. S. Chettoe, B.Sc., M. Inst. C.E.

June 2 (Tues.).† (5.30 p.m.) Paper for discussion: "**Earthwork in Embankments,**" by R. M. Wynne-Edwards, D.S.O., M.C., M.A., M. Inst. C.E.

### RAILWAY ENGINEERING SECTION.

Apr. 28 (Tues.).† (5.30 p.m.) Paper for discussion: "**The Repair of War Damage to Railway Way and Works in the London Area, 1940 and 1941,**" by Arthur Dean, M.Sc., Assoc. M. Inst. C.E.

### ANNUAL GENERAL MEETING.

The Annual General Meeting of Corporate Members will be held on Tuesday, 23 June, at 5.30 p.m.

*The Meeting will be preceded by a ballot for the election of new members.*

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† Advance copies, for those who intend to be present, will be available about a fortnight before the meeting, and may be obtained upon application to the Secretary.

# SPECIAL ANNOUNCEMENTS.

## ROYAL AIR FORCE VOLUNTEER RESERVE.

In addition to the openings for Civil Engineers announced in the "Notices" Section of the February, 1942, Number of the Journal (p. [2]), the Air Ministry informs The Institution that the R.A.F. Works Units have openings for a limited number of mechanical and electrical engineers with power house plant, electric distribution systems and electric apparatus experience, and for a number of mechanical engineers with experience on the operation and maintenance of civil engineering plant. Selection will normally be confined to candidates between the ages of 26 and 35 years, but candidates outside these age-limits may be considered if they have exceptional qualifications and experience.

Any members of The Institution who desire to apply may forward their names to the Secretary of The Inst. C.E., with *brief* details of their engineering training and experience, with a view to transmission of such applications to the Air Ministry.

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# GENERAL ANNOUNCEMENTS.

## BALLOT FOR THE ELECTION OF THE COUNCIL.

A voting paper and covering letter in regard to the Ballot for the election of the Council for 1942–43 are sent with this Number of the Journal to home Corporate Members.

## THE JOURNAL.

The next Number of the Journal will be published on the 15th June.

## JAMES ALFRED EWING MEDAL.

On the joint nomination of Professor C. E. Inglis, President of The Institution, and the late Sir William Bragg, Acting President of the Royal Society, the Council have awarded the James Alfred Ewing Medal for 1941 to Dr. Frederick William Lanchester, F.R.S.

## MINISTRY OF HOME SECURITY: RESEARCH AND EXPERIMENTS BRANCH.

Copies of a revised edition of the following Bulletin (ref. p. [8] of the "Notices" Section of the December 1940 Number of the Journal) are

now available to members, by permission of the Ministry of Home Security, upon application to the Secretary of The Institution :—

Bulletin No. C.10 (Revised). "Translucent Substitutes for Glass."

(Superseding Bulletin No. C.10 entitled "Flexible Substitutes for Glass.")

## AERODROME ABSTRACTS.

Nos. 14–39 (Vol. I, No. 2) of Aerodrome Abstracts are reprinted at pp. [14]–[23], *post*, by permission of the Air Ministry and the Department of Scientific and Industrial Research. Nos. 1–13 appeared in the March Journal (pp. [15]—[21]).

## TRANSFERS, ELECTIONS, AND ADMISSIONS.

Since the 10th February 1942, the following elections have taken place :—

| *Meeting.* | *Members.* | *Associate Members.* |
|---|---|---|
| 10 March, 1942. | 1 | 12 |

and during the same period the Council have transferred 3 Associate Members to the class of full Members, and admitted 48 Students.

## DEATHS AND RESIGNATION.

### Deaths.

| | |
|---|---|
| Bragg, Sir William Henry, O.M., K.B.E., M.A., D.Sc., Sc.D., LL.D., D.C.L., F.R.S. | *Hon. Member.* |
| Elliott-Cooper, Sir Robert Elliott, K.C.B. | ,, |
| Buckwell, George William | *Member.* |
| Coutts, John Campbell, B.Sc. | ,, |
| Bowden, Frederick William | *Associate Member.* |
| Daly, Arthur Joseph, B.E. | ,, ,, |
| Flowers, Charlie, B.Sc. | ,, ,, |
| Frew, David Benny, M.C., B.Sc. | ,, ,, |
| Goldthorp, Alfred Reginald, B.Sc. | ,, ,, |
| Greig, Albert Edward | ,, ,, |
| *Hamilton, John Jackson, B.A. | ,, ,, |
| Hogg, William, B.A.I. | ,, ,, |
| Lee-Norman, Francis Thomas, M.C., B.A. | ,, ,, |
| Parker, Thomas Wint Weir | ,, ,, |
| Pratt, Hartley Blyth | ,, ,, |
| Shakespeare, John George | ,, ,, |
| Sayer, John Joselyne, B.Sc. | *Student.* |

* On Active Service.

### Resignation.

| | |
|---|---|
| Hilton, Harold Cunliffe | *Associate Member.* |

## A SELECTIVE LIST OF RECENT ADDITIONS TO THE LIBRARY.

[Journals, Proceedings of Societies, etc., are not included.]

AIRPORTS. *See* LAND DRAINAGE.

ARCHITECTURE. *See* PUBLIC WORKS.

BRIDGES. *See* SPECIFICATIONS.

CATHODE RAY TUBE. PARR, G. "The Cathode Ray Tube and its Applications." 2nd ed. 1941. Chapman & Hall. 13*s.* 6*d.*

*CONCRETE. UNITED STATES BUREAU OF RECLAMATION. "Concrete Manual." 3rd ed. 1941. The Bureau, Denver, Colorado. No price.

CORDAGE. *See* ROPES.

ECONOMICS. LEAGUE OF NATIONS. "World Economic Survey, 1939–41." 1941. Allen & Unwin. 10*s.*

EMULSIONS. BERKMAN, S., and EGLOFF, G. "Emulsions and Foams." 1941. Reinhold Publishing Corp'n. 51*s.*

ENGINEERING. *See* PROFESSIONS.

*GAS AND GAS SUPPLY. "*Gas Journal* Calendar and Directory, 1942." Walter King. 21*s.*

GAUGES. *See* MEASUREMENT.

*LAND DRAINAGE. ARMCO INTERNATIONAL CORPORATION. "Airport Drainage." 1941. The Corp'n, Middletown, Ohio. No price.

MACHINE TOOLS. INSTITUTION OF MECHANICAL ENGINEERS and INSTITUTION OF PRODUCTION ENGINEERS. "Acceptance Test Charts for Machine Tools, Part II." 1941. The Institutions. 5*s.* 6*d.*

MATHEMATICS. WALLING, S. A., and HILL, J. C. "Aircraft Mathematics." 1942. Cambridge University Press. 2*s.* 9*d.*

MEASUREMENT. FARLEY, H. E. J. "Elementary Measurement and Gauging." 1941. Blackie. 2*s.* 6*d.*

MECHANICAL ENGINEERING. *See* PROFESSIONS.

MICROSCOPE. BECK, C. "The Microscope. Theory and Practice." 1938. R. and J. Beck. 7*s.* 6*d.*

MODEL ENGINEERING. GREENLY, H. "Model Engineering." 8th ed. 1941. Cassell. 10*s.*

PLYWOOD. WOOD, A. D., and LINN, T. G. "Plywoods: their Development, Manufacture, and Application." 1942. W. and A. K. Johnston. 25*s.*

PROFESSIONS. ATHERTON, W. H. "Mechanical Engineering: the Profession and its Opportunities." 1940. Pitman. 4*s.*

—— HOOVER, T. J., and FISH, J. C. L. "The Engineering Profession." 1941. Oxford University Press. 30*s.*

*PUBLIC WORKS. SHORT, C. W., and STANLEY-BROWN, R. "Public Buildings. A Survey of Architecture of Projects constructed by Federal and other Governmental bodies between the Years 1933 and 1939." 1939. Govt. Printing Office, Washington. $2.50.

ROADS. *See* SPECIFICATIONS.

ROPES AND ROPEWAYS. GRANT, D. E. "Wire Ropes and Cordage." 2nd ed. 1941. Dixon Corbitt, Ltd. Gateshead. No price.

SEWAGE DISPOSAL AND SEWERAGE. WHYATT, H. G. "Sewers and Sewerage." 4th ed., revised by J. V. Oldfield. 1941. Pitman. 3*s.* 6*d.*

SOILS. JENNY, H. *"Factors of Soil Formation." 1941. McGraw-Hill. 24s. 6d.

—— MACAULAY INSTITUTE FOR SOIL RESEARCH. "Collected Papers." Vol. 1. 1938. The Institute, Craigiebuckler, Aberdeen. 21s.

SPECIFICATIONS. PUBLIC ROADS ADMINISTRATION, U.S.A. "Specifications for Construction of Roads and Bridges in National Forests and National Parks, 1941." 1941. Supt. of Documents, Washington. 1 dollar.

WATER. DORSEY, N. E. "Properties of Ordinary Water-Substance." 1940. Reinhold Publishing Corp'n. 90s.

(* *The foregoing books, with the exception of those marked with an asterisk, may be borrowed from the Loan Library.*)

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# LOCAL ASSOCIATIONS.

The following arrangements have been made for forthcoming meetings of the Local Associations. The arrangements are in the hands of the Committees of the Associations concerned and all communications respecting them should be addressed to the respective Honorary Secretaries :—

### NORTHERN IRELAND ASSOCIATION.

Apr. 20. Annual General Meeting.

### EDINBURGH ASSOCIATION.

Apr. 15. Annual General Meeting and "Excavation Work", by J. L. White, B.Sc., Assoc. M. Inst. C.E.

### NORTH-WESTERN ASSOCIATION.

Apr. 25. "Post-War Planning and Reconstuction", by H. J. B. Manzoni, C.B.E., M. Inst. C.E.

### SOUTH WALES AND MONMOUTHSHIRE ASSOCIATION.

Apr. 18. Annual General Meeting and "Concrete and the Resident Engineer", by D. F. Wilkin, B.Sc., Stud. Inst. C.E.

### SOUTHERN ASSOCIATION.

Apr. 25. "The Analysis of some Engineering Problems associated with Clay Soils", by A. W. Skempton, M.Sc., Assoc. M. Inst. C.E. (at Portsmouth).

### YORKSHIRE ASSOCIATION.

May 9. Discussion on "Mining Subsidence and some Drainage Problems arising therefrom", by H. J. Paul, M. Inst. C.E. (at Sheffield).

June 6. Annual General Meeting and Luncheon (at Sheffield).

## REPORTS.

*Bristol and District Association.*

On Thursday, 5 March, at Bristol, Mr. H. C. M. Austen, C.B.E., M. Inst. C.E., read a Paper on "Mauritius Harbour."

*Edinburgh and District Association.*

The film illustrating the Failure of the Tacoma Narrows Suspension Bridge was shown at a meeting held on Wednesday, 11 March.

*Northern Ireland Association.*

On Monday, 23 February, a Paper on "National Planning" was read by Captain K. C. Brown.

*South Wales and Monmouthshire Association.*

On Saturday, 21 February, at Swansea, Mr. J. A. Posford, M.A., Assoc. M. Inst. C.E., read a Paper on "The Construction of an Arch Dam for Temporary Work."

*Yorkshire Association.*

On Saturday, 28 February, at Sheffield, the film illustrating the Failure of the Tacoma Narrows Suspension Bridge was shown, and on Saturday, 7 March, at a joint meeting at Sheffield with the Yorkshire Branches of the Institution of Mechanical Engineers and the Institution of Structural Engineers, the Thomas Hawksley Lecture on "A Century of Tunnelling", by Mr. W. T. Halcrow, was repeated.

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## Conference of the Institutions of Civil, Electrical, and Mechanical Engineers on

## "AIR-RAID PRECAUTION MEASURES AND THE ENGINEERING INDUSTRY,"

Held on 9 December, 1941.

**Summary of Addresses.**

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### "The Effect of High Explosives on Structures."

By Professor J. D. Bernal, M.A., F.R.S.

An understanding of the mechanism of damage by high explosives is invaluable when designing means for minimizing such damage.

The subject has been studied in three ways: (1) Laboratory work; (2) Field work on full-scale experiments unsuited to the laboratory; (3) Recording at site the effects of air-raids and the effects of particular bombs on structures.

Observations of air-raids reviewed in the light of large- and small-scale experiments have made it possible to predict with confidence from laboratory tests what will happen in the field. What may be called a practical science of explosives has thus been built up, and it is now possible to assess the strength of a structure required to resist a given weight of explosive under given conditions.

It is not possible here to give a quantitative picture, but a rough idea is possible of the character of damage (excluding fire).

The main effects of explosives are covered by describing the arrival of the bomb, and then the three chief mechanisms by which mines and bombs cause damage :—(1) blast ; (2) bomb fragments ; (3) earth shock when a bomb explodes in the ground.

Mines usually have a reduced speed of falling and depth of penetration ; they are intended to explode outside buildings or on ground and achieve their object entirely by blast.

Penetrating bombs range from the 50-kg. bomb, used in large quantities, to large bombs exceeding 1,000 kg. All these have cases sturdy enough to penetrate buildings.

A point to stress is not how far a bomb can penetrate a building or the ground, but how far it goes before exploding. This is determined not by the penetrating power, but essentially by the kind of fuse it carries.

Consider the explosion of the bomb itself. If this occurs in the air the expanding gases cause the case to swell and so thin it to breaking-point. The fragments of the case are not distributed evenly, but fly into three main groups :—(1) those shot off at right angles to the side of the bomb, forming the main fragment-zone ; (2) tail fragments—usually light ; (3) nose fragments—usually heavy.

A wall near an exploding bomb receives fragments from the main zone, and a hole may be punched through. The momentum of fragments is large, and massed fragments have been known to shift concrete blocks.

The released gases expand initially at a speed of about 6,000 feet per second. Their impact on the surrounding air produces a blast-wave in which pressure rises instantaneously to its maximum value, falls off gradually, and is followed by a suction phase of longer duration but smaller magnitude. With increasing distance both pressure and suction fall off—the pressure more rapidly—and the durations increase. Blast pressures on structures are different from the pressures ordinarily met in engineering because they act for so short a time. Thus a blast peak pressure of 20 lb. per square inch has quite a different effect from a static pressure of 20 lb. per square inch.

It is possible to analyse the reaction of a structure to the sudden short pressure and to estimate fairly accurately how a wall of given construction will react to blast of any character, by means of a calculation using the equivalent static pressure. High-frequency systems become subject to a greater equivalent static pressure than those with low frequencies, because the high-frequency ones move more rapidly, thus absorbing more energy of the blast. A very heavy structure reflects practically all the blast wave, and the structure is little affected.

Damage to light structures can occur by a resonance effect if the half-period of the structure is of the same order as the time-interval between

maximum pressure and maximum suction, the elastic rebound of the structure coinciding with the suction phase of the blast.

The type of failure of buildings under blast depends on the distance from explosion. Houses near the bomb collapse, the walls being pushed away by the pressure phase. Farther away damage is caused by the suction phase. When the external pressure is reduced the air confined within the building presses on the walls, and if the suction is strong enough walls may even be pushed out. The shielding effect of other buildings is marked, especially for the pressure phase, so that damage is usually confined to roofs and upper floors of more distant buildings.

Blast is most important when the explosion is confined; its multiple reflexions from walls, floor, and roof prolong the period during which pressure acts. Since the amount of damage to the structure is determined by the impulse, that is, the pressure multipled by the time for which it acts, the increased duration due to reflexion increases the destruction. This destruction is therefore diminished by the flying off of light roofs, and less so by bursting of doors and windows.

Primary damage is due to the direct effect of blast pushing over part of the structure; secondary damage is caused by subsequent collapse of other parts. With existing buildings not much can be done to diminish the primary damage, but a considerable reduction of secondary collapse can be obtained by proper strengthening. This can clearly be seen by comparing fully-framed structures with those having load-bearing walls which often exhibit spreading or secondary collapse.

When a bomb explodes in the earth, the case breaks into a few large fragments and the expanding gases make a spherical cavity in the surrounding earth. At the same time a shock-wave travels out in all directions. On arrival at the surface the wave is reflected as a tension wave, a conical scab being thrown up, leaving a crater. The type of crater depends on the depth of explosion. Debris may fall back, leaving a visible crater much smaller than the true one, or the bomb may be so deep as merely to heave and crack the ground, the explosive gases escaping and leaving a "camouflet."

The shock-wave in the ground travels at different velocities in different layers and at different depths, and at some distance from the explosion the originally simple shock wave becomes a complex train of waves. Near the bomb considerable displacements of surrounding earth occur. These are partly elastic and partly plastic, so that ground may be moved several inches whilst the final displacement shown is small. A point fairly near a bomb has a violent upward jerk followed by a comparatively slow horizontal movement outwards and a subsequent partial recovery. Both vertical and horizontal movements fall off rapidly with distance.

Near the bomb, buildings are damaged by plastic displacement, whilst farther away they are subjected to shaking and collapse may occur through resonance effect, although damage is usually limited to cracking. The

shock wave is transmitted into the buildings through the foundations and is reflected as a tension wave from any free surface. Thus roofs are often lifted and may be thrown clear of the walls in small buildings, and the wall farthest away from the explosion may collapse although the nearer part of the building is distorted but not seriously damaged.

The effects of ground shock are more serious for underground structures than for surface ones. In an underground structure, the force applied to the nearest wall is transmitted through the roof and floor, and caving-in may occur, leading also to roof collapse. However, structures in which floor, walls, and roof are well tied together can undergo considerable distortion without complete collapse.

## "The Design of Protective Structures and the Defence of Industry,"

By Professor J. F. Baker, O.B.E., M.A., Sc.D., D.Sc.

Principles of structural design for protecting industry from air attack have now emerged which, though unfamiliar in normal engineering practice, can claim recognition as rational. A bomb exploding near a structure liberates energy so violently, and for such a short time, that it is the dynamical properties of the structure that are tested, and strength under simple static loading becomes relatively unimportant. For effective resistance the resilence of the structure is what matters, coupled with provision against failure by shear. Moreover, whilst ductility in material and continuity in structural form are essentials, these must be combined with mass if the structure takes a form, such as a wall, which will directly oppose the blast. This is because the maximum work per unit area of surface which can be done by blast on the lamina is inversely proportional to the weight of the lamina per unit area.

The means for pursuing the study of principles and their application have included testing up to full-size trials, observation, critical and satistical analysis of results of air-attack on structures, and mathematical work on the physics of explosion. As the practical outcome of this research it remains to show how protective structures may combine, with economy of labour and such materials as are available, the qualities of weight, resilience, and resistance to shear, and how industrial buildings may be similarly endowed.

Well-placed shelters for the protection of workers during the alert are an important feature in industrial defence. A satisfactory form has been evolved, identical in outward appearance with the original brick shelter [1] but incorporating vertical steel reinforcing-rods. The rods are carried into the roof to tie it down. Similarly the rods are best taken into the

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[1] For further information on reinforced brick shelters see H.S.C. No. 290/1940 and reprint in the Technical Press of Research and Experiments Dept., Bulletin No. C.20.

floor, producing in effect a box section. For ease of placing the reinforcement the "Quetta bond" of brickwork has been useful. Such shelters have proved highly satisfactory, not only against bombs exploding on the ground-surface, but also in resistance to the earth movements set up by bombs exploding after penetrating some distance into the ground near the shelter.

Structural design for strengthening floors to carry debris loading and for stability under earth shock has also been rationalized. Deflexions which would normally be regarded as excessive are permissible if the weight of the collapsing superstructure is sustained. The design must be redundant, continuity being provided wherever possible, and a ductile material used so that large deformations can occur without failure. In addition to supporting the estimated vertical debris load, a horizontal load must be sustained of 200 lb. per foot run applied at ceiling-level and acting on any side. The total maximum stresses may exceed the usual working stresses by not more than 33⅓ per cent. in cases where the excess is due solely to the horizontal loading.

In small dwelling-houses with wood joist floors a braced frame is recommended, built independently of the existing structure[1].

The fully-framed building, being highly resistant to collapse, is eminently suited for providing air-raid shelter. On certain floors it affords a substantial degree of overhead protection and panel walls of the usual thickness offer useful resistance to glancing blows. Fire-resisting framed construction gives useful security from the primary effects of a direct hit if adequate cover extends over the whole floor on which the protected accommodation is required. Any additional lateral walling required for the protected accommodation is unlikely to increase the stresses beyond the limitations of B.S.S. 449 (Revised). Protection from the secondary effects of blast is provided in the usual manner[2]. It is desirable to remove any doors and internal partitions weighing less than 60 lb. per square foot.

The steel "table" or "Morrison" shelter for use in dwelling-houses is a direct application of the principle of ductility[3].

For vital factories the fully-framed structure is the only suitable type. Steel and reinforced-concrete structures, if suitably designed, are satisfactorily resistant to collapse[4].

Most fully steel-framed single-storey factory buildings are reasonably resistant to structural failure. The damage from a near miss or direct hit

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[1] For further information see reprint in the Technical Press of Research and Experiments Dept., Bulletin No. C.14.

[2] For further information see reprint in the Technical Press of Research and Experiments Dept., Bulletin No. C. 13.

[3] For further information see reprint in the Technical Press of Research and Experiments Dept., Bulletin No. C.16; and the pamphlet "Shelter at Home," issued by the Ministry of Home Security.

[4] For further information see Wartime Building Bulletin No. 17.

is usually confined to the lighter elements, the structural framework escaping undamaged. It is important to design so that collapse of structural steelwork will not spread from the failure of a single stanchion[1].

A bomb hitting a single-storey factory may explode on the roof, between the roof and floor, on the floor or below it. Except in the last event fragments fly all around, injuring men and machines. An important function of protective devices is to limit the effects of these bomb fragments and of objects thrown about by blast, by reducing the vulnerable area, that is, the area within which a bomb must fall to cause injury. To protect any comparatively small but very vital item, a portal-framed structure is most suitable. Similarly reinforced-concrete arch structures are used to cover turbo-alternators and other electric plant. Walls, without reinforcement, carrying a heavy slab roof are quite unsuitable, as also are structures incorporating panels of thin, light material.

Overhead cover protects against bombs exploding in the air almost overhead and from crater debris. In lofty sheds, portal structures are often the best solution, but they are relatively costly and not suitable for extensive use. In practice walls are the most useful form of protection. A protective wall should stop bomb fragments and crater debris flung laterally; it should not disintegrate under blast or be overturned by earth shock. These requirements are met by reinforced-concrete walls 12 inches thick, or reinforced brick walls 13½ inches thick, with adequate foundation or width of base. For factories operating on line production a special form of movable wall has been designed. Fire-stop walls should, whenever possible, function also as protective walls and should, therefore, be designed as such. Although a fire-fighting organization remains the chief safeguard from damage by fire, its task is eased by structural barriers opposing fire spread.

The criterion of proper protection is that, having regard to war hazards, the total probable output over a period of all existing factories shall be thereby increased by a greater amount than if the work had gone into building new factories which have to be equipped with machine-tools. The production methods in the factory must be studied by the planner, who must appreciate the degree of importance of each part of the factory and of each item of plant in it. Whatever degree of protection is desired, it must be provided economically, and a simple but sound guide to height and spacing of wall systems has been worked out.

The economic standard of protection depends ultimately on the scale of air attack, but the proportion of material and labour which should be used on protection is independent of the total amount available after provision has been made for housing entirely new processes.

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[1] For further particulars see reprint in the Technical Press of Research and Experiments Dept., Bulletins No. C. 5, 8, 12, 15, and 19.

## "A Survey of the Gas Contamination Problem in the Engineering Industry, with Special Reference to Electrical Machinery."

By Major J. W. Martin, M.B.E., B.Sc., A.I.C.

The principles of gas decontamination are well established, but in applying them to industrial plant the effects of gas contamination should not be exaggerated.

The survey dealt with the effects of gas contamination on the properties of materials and the functioning of machines; not on the personnel operating the machines, though the danger to the latter resulting from vapour from contaminated machines is considerable.

The chief danger in factories is the splashing of machines and installations with persistent gases—the area of contamination being fairly localized. Roughly an area of 120 square yards is grossly contaminated by a 50-kg. explosive gas-bomb. These bombs have little disruptive effect. Protection against splashing, which can be localized by protective walls, screens, hoods, or even a simple cover for vital machines, is relatively simple.

The chief concerns in the event of gas contamination are the area and degree of concentration, the maintenance of production, the danger to operatives working contaminated machines if the running of the plant is continued, and to operatives in adjacent, non-contaminated parts of the building.

Much plant can be contaminated without being otherwise damaged; thus its mechanical functioning need not be prevented. The chief danger is to operatives exposed to vapour. Concentration of vapour depends on the temperature and humidity of the atmosphere and on air-movements. Adequate ventilation is required to deal with concentrations of vapour.

Particular problems arise with the insulation of electrical machinery. As there is no marked corrosion of metal, parts of metal and other non-porous materials can be dealt with by repeated swabbing with solvents. Porous materials may be decontaminated by bleach paste and weathering; the latter is simplest so long as there is no danger of contact with personnel.

An important factor in electrical work is the specific resistivity of liquid gases, owing to the danger of flash-overs. Experiments suggest that there is little danger of this even when there is a direct path of the contaminating liquid between electrodes. Gross superficial contamination of rotating electrical machinery may be removed by swabbing; residual contamination will be removed by running the machine. Even when field coils and armatures are contaminated, the penetration of the insulation will not be considerable if running is continued.

Out-of-door substations and transforming plant are more liable to contamination. Much of the plant can be left to weather after removing the liquid from accessible parts.

Contamination on secondary batteries of the lead-acid type can occur only if a bomb enters the battery-room. Spray arresters on the cells provide some protection, which may be increased by the provision of another, larger cover above and clear of spray arresters. Interference with the functioning of the cells that are not physically damaged is unlikely, any visible liquid being removed by swabbing with solvents. When the electrolyte is contaminated it will be necessary to renew the acid. Good ventilation is necessary to avoid concentrations of vapour and contamination of neighbouring rooms.

The operation of control panels should not be interfered with by splash contamination, which may be dealt with by systematic treatment with solvents. Exposed insulated cables and wiring can be treated with bleach paste, whilst portions of the wiring with absorbent insulating materials, if grossly contaminated, must be cut out, though there should be no immediate breakdown of insulation. Lighter contaminations can be left to weather, provided attention is paid to the danger from vapour.

Delicate instruments, such as relays, voltmeters, and ammeters, are usually well protected, and if undamaged the casings can be treated with solvents. When damaged they are a salvage-cum-decontamination problem.

Much could be done to localize contamination in open-type telephone exchanges by the use of partitions, screens, and curtains. Automatic apparatus will probably continue to function, vapour danger to the staff being the chief thing to guard against. Weathering would be helped by suitably placed heaters, some form of extractor being used.

The exposed portions of manual switchboards must be treated rapidly with solvents. If the liquid reaches the more vital parts there is little use in trying to decontaminate them. The problem becomes one of salvage.

In factories producing electrical equipment, the multiplicity of stores and partially assembled components require particular attention. Stores generally and individual items in stores should be protected, and it is simpler to remove cartons that become splashed than to decontaminate a large number of components.

Small items may be decontaminated by immersion in briskly boiling water for 30 minutes, or by hot air, unless very heavily contaminated.

It is probably best to concentrate on getting the assembly shop into working order, and not to attempt detailed decontamination of complicated assembled parts. These should be treated as a salvage problem.

Like blister gases, tear gases are easily absorbed by porous materials. They are generally more corrosive to metals than is mustard gas, and should be removed by swabbing with solvents or by treatment with caustic soda in methylated spirit. Porous materials will have to be left to weather for long periods. Large areas, such as floors, could have an application of lime slurry.

In conclusion, the chances of contamination causing serious dislocation

of industry are not high, and risks can be appreciably reduced by relatively simple means. Where contamination of plant occurs it need not mean closing the works for long periods. It is advisable to replace the intricate and complicated instruments and components of plant that become contaminated. Emphasis should be on putting the plant into operation, contaminated work in progress being dealt with as a salvage operation.

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# AERODROME ABSTRACTS.*

**Compiled by the Department of Scientific and Industrial Research (Road Research Laboratory) and issued in Collaboration with the Air Ministry.**

*The Road Research Laboratory and the Ministry of War Transport jointly compile "Road Abstracts" to which reference is made.*

1942, Vol. I, No. 2 (March). Abstracts Nos. 14–39

*Note.*—The abstracts purport to be fair summaries of the original literature, but no responsibility can be accepted by the Department of Scientific and Industrial Research for the accuracy of authors' statements or for their opinions.

Publication—Alternate months. A subject- and name-index will be issued annually.

14. **Construction of Military Air Fields** : C. T. NEWTON : *Civ. Engng, Easton, Pa*, 1941, 11 (4), 207–11. The Air Corps and the Corps of Engineers of the U.S. ARMY co-operate closely in planning and constructing permanent military aerodromes. The choice of site and lay-out of the aerodrome are the responsibility of the Air Corps, while the construction work is done by the Corps of Engineers. The general construction procedure is briefly described, and details are illustrated of drainage systems and types of surfacing at some existing military aerodromes. To meet the need, under war conditions, of temporary aerodromes that must be rapidly constructed, an Engineer Regiment (Aviation) has recently been organized. It is equipped with modern machinery for all types of construction work, and with mechanical transport for rapidity of movement. The unit is armed. In peace time these units are trained in the construction and maintenance of aerodromes. In wartime their main duties are as follows : (1) Improvement or provision of advanced aerodromes. (2) Im-

provement or provision of roads to such aerodromes. (3) Provisions for gas- and bomb-proofing essential parts of the installations. (4) Camouflage of advanced and other aerodromes. (5) Assistance in the defence of advanced aerodromes from ground and air attack. (6) Maintenance and repair of aerodromes, especially after air attack.

15. **Cardinal Principles in Location and Design of Commercial Airports and their Application to the Washington Airport** : H. H. Houk : *Proc. Highw. Res. Bd, Wash.*, 1940, 20, 455–80. The influence of meteorological and soil conditions on the choice of site, and factors deciding the size and shape of the airport area, the number, length, and direction of the runways, are discussed at length. Examples of runway arrangement and the design of taxiways and loading aprons are described. The "approach zone" for normal usage runways is required to be 500 ft. wide at the end of the runway and increases in width to 2,500 ft. two miles away. For blind landing the "approach zone" is 1,000 ft. wide at the end of the runway and 4,000 ft. two miles distant. The design and construction of the Washington National Airport are described in detail.

16. **The Washington National Airport** : R. S. Thomas ; **Choice of Surfacing Types for Airports** : H. H. Houk : with foreword by B. E. Gray : *Asphalt Institute : Construction Series* No. 54. New York, 1941 (Asphalt Institute), 9 in. by 6¼ in., pp. 28, ill., unpriced. In the foreword, the influence on the design of aerodrome runways of the volume of traffic, and the maximum static loads to be sustained by the runway are briefly discussed in relation to the bearing capacity of the subgrade, the thickness of bituminous surfacing necessary, and the choice of type of surfacing. Four classes of bituminous surfacing are described with reference to the conditions for which they are most suitable. The first paper contains an account of the design and construction of the Washington National Airport, including reasons for the choice of site, method of draining and filling the marshy ground, stabilizing the subgrade with granular materials, thickness and type of bituminous surfacing used, equipment employed, and costs. The second paper is concerned with the principal factors involved in choosing the most suitable and economical surfacings for runways. The first requirement is adequate stability of the subgrade, and to ensure this laboratory studies should be undertaken to determine the principal characteristics of the natural soil. Methods and costs are given of soil stabilization with granular materials. The second requirement is a smooth, non-skid surfacing in both dry and wet weather ; and a third important item is the elimination of glare. Stress is laid on the necessity for employing trained personnel, close control of materials and construction methods, use of local materials whenever possible, and selection of the most suitable type of bituminous surfacing for both the weather conditions at the time of construction and the conditions under which it is to be used.

17. **Civil Airport Development in the United States**: ANON.: *Engineer, Lond.*, 1941, **172** (4467), 116–7; (4468), 130–2; (4469), 151; (4470), 164–5. A review of U.S.A. practice in the planning, design and construction of civil airports is based on reports of the U.S. CIVIL AERONAUTICS ADMINISTRATION. (See also Abstract No. 1 and *Road Abstr.*, 1941, **8**, No. 87.)

18. **Bomber Flying Fields: the Need for Scientific Design of Pavements on Military Flying Fields**: W. R. MACATEE: *Asphalt Institute: Construction Series* No. 59. New York, 1941 (Asphalt Institute), 10¾ in. by 7¼ in., pp. 19, ill., unpriced; **Asphalt Pavements' Beneficial Confining Effect**: W. R. MACATEE: *Asphalt Institute: Construction Series* No. 59-A. New York, 1941 (Asphalt Institute), 9 in. by 6 in., pp. 4, fig. 5, unpriced. In the first of these two publications, the importance is stressed of constructing by scientific methods foundations of adequate bearing capacity and asphalt surfacing of the necessary thickness to support the increasingly heavy loads imposed by bombers on aerodrome runways, taxi strips, and aprons. The advantages of using bituminous surfacings are that (1) non-rigid surfacings make use of subgrade strength, and may therefore require less thickness than the minimum necessary for any rigid surfacing, (2) non-rigid surfacings adjust themselves more easily to unequal settlement, (3) the strength of bituminous surfacings can be readily increased by adding thin layers of asphaltic concrete, and (4) the cost of maintenance is low. *Thickness of surfacing.* The minimum thickness of asphalt surfacing for use by bombers is 3 in., which is necessary to provide a waterproof cover for the subgrade, sufficient lateral stability to prevent surface abrasion and a smooth non-skid surface that will shed water quickly. The maximum unit pressure likely to be imposed by any bomber in the near future has been calculated to be 90 lb./sq. in. assuming the weight to be 200,000 lb. and the area of the tire imprint 1,200 sq. in. for each main wheel. Although this unit pressure is not necessarily greater than that of a lighter aeroplane, the area of tire imprint of a bomber is important, since in a cohesive soil the bearing capacity per sq. in. is directly related to the size of the loaded area. Apparatus for testing the bearing capacity of soils is illustrated and described. It consists of a hydraulic jack by which pressure is imposed on a metal plate equal in area to the tire imprint or on three smaller plates. Previous publications by the ASPHALT INSTITUTE describe the method fully (see *Road Abstr.*, 1942, **9**, No. 33). The soil should be tested in its poorest condition, and only soils having a low capillary attraction are permissible as subgrade for asphalt surfacings. As a result of tests it was found that a subgrade with a bearing capacity of 60 lb./sq. in. requires a surfacing of slightly less than 3 in. in thickness. For every decrease of 10 lb./sq. in. in bearing capacity, one inch approximately of surfacing is required, up to 6 in. for a subgrade of which the bearing capacity is 30 lb./sq. in. It is recommended that

wherever possible the strength of the runway should be attained by improving the bearing capacity of the subgrade rather than by increasing the thickness of the surfacing. *Specification for hot-mix asphaltic concrete surfacings* (coarse-graded aggregate type). The surfacing shall be laid in two courses on a subgrade primed with bitumen and sealed with a coat of cut-back bitumen and cover of mineral aggregate. The base course and wearing course shall have respective thicknesses of 1½ in. and 1½ in., 2½ in. and 1½ in., 3 in. and 2 in. or 3½ in. and 2½ in. according to the total thickness of the surfacing. *Materials.* Separate specifications are given for the coarse and fine aggregates to be used. In the base course the composition of the mix, by weight, shall be as follows: 20 to 30 per cent. of aggregate passing 1½-in., retained on 1¼-in. sieve, 25 to 40 passing ¾-in., retained on ¼-in., 5 to 15 passing ¼-in., retained on 10-mesh sieve, 20 to 35 passing 10-mesh, retained on 200-mesh, and 0 to 5 passing 200-mesh sieve; and 4 to 7 per cent. of bitumen. In the wearing course mineral filler shall be added, and the proportions shall be 15 to 25 per cent. passing 1¾-in., retained on ¾-in., 20 to 35 passing ¾-in., retained on ¼-in., 5 to 15 passing ¼-in., retained on 10-mesh, 25 to 35 passing 10-mesh, retained on 200-mesh, 4 to 6 passing 200-mesh; and 5 to 8 per cent. of bitumen. The asphaltic cement shall have a penetration of 120 to 150 at 77° F. (100 g., 5 sec.). Standard tests (mostly A.S.T.M.) are quoted for all materials. *Methods.* Bitumen shall be heated at the plant to 225° to 325° F. Aggregates shall be dried and heated to 225° to 300° F. The hot aggregate, weighed in the correct proportions, with filler if required, shall be mixed for at least 15 sec. before the addition of the bitumen and for at least 30 sec. afterwards. Mixtures shall be delivered on the job at a temperature of 225° to 275° F. All equipment, general methods and conditions of work and methods of spreading, jointing and compacting the different courses are fully specified. After final compression each course shall conform within ¼ in. to the average thickness specified, and the surface shall have no depression exceeding ⅛ in. measured with a 10-ft. straight-edge parallel to the centre line of the road. The finished base course shall not at any point have a density of less than 94 per cent., nor the wearing course of less than 95 per cent. of the maximum obtainable in a surfacing having no voids, composed of the same materials in the same proportions. *Factor of safety.* The second publication shows that an ample margin of safety is provided by the confining effect of the surfacing on the subgrade, which was not included in the calculations. Equipment is described with which this effect can be measured in the field. Reference is made to the work of F. Burggraf on the effect of overlying surfacings on both cohesive and non-cohesive subgrades (see *Road Abstr.*, 1941, 8, No. 214).

19. **Modern Mechanical Earth-Moving in the Construction of an Aerodrome at Sabang**: Nederlandsch-Indische Wegenvereeniging: *Publicatie No. 201.* Bandoeng, 1941 (Nederlandsch-Indische

Wegenvereeniging), 8¼ in. by 5¾ in., pp. 20, fig. 8, unpriced. The construction of an aerodrome on the coral island of Sabang presented special difficulties. The topsoil, nowhere thicker than 30 cm. (12 in.), had to be removed, and the underlying " karang " is extremely difficult to handle, being too hard for the use of manual labour and too soft for explosives. Experiments made with the latter were disappointing, and the porosity of the material made large quantities of explosive necessary. The following machinery was therefore used :— (1) Three track-laying tractors protected by crankcase guards as " karang " tends to break into large pieces, (2) two carry-all scrapers, (3) one heavy duty rooter, (4) one cable-controlled angle-dozer and (5) one transportable air-compressor. Electric lighting was provided for night work. About 929,000 cu. yd. of soil were moved. If necessary the rooter was driven several times over the same ground, and explosive was used only in exceptionally hard places. Details are given of the employment and maintenance of the machinery, and of repairs and replacements most frequently required. The following facts were noted : (1) The most powerful machinery is most economical in use, and (2) the filling of ravines by bulldozers did not cause any subsequent settlement. This is probably due to the compaction effected by the tractors.

20. **Airplane Impact Loads on Buried Pipes** : R. G. Scott : *Civ. Engng, Easton, Pa*, 1941, **11** (9), 524–5. The stresses produced by aircraft in landing are important in deciding how deep pipes should be buried. The loads are computed that are transmitted to vitrified clay pipe of different sizes at depths varying from 2 to 9 ft. by a plane having a gross weight of 52,000 lb. and delivering a vertical impact calculated to be 10,000 lb. These loads, added to the earth loads, are compared with the A.S.T.M. crushing strength of the pipes. The results show that clay pipe can be placed safely at any depth of cover greater than 2 ft. In practice the impact load would be less than calculated, since (1) when the plane first touches the ground the load is partly air-borne, and (2) there is an interval before the load reaches the pipe, during which the plane has moved on. In the case of paved runways, little or no stress would be transmitted to the earth and pipe.

21. **Mole Drainage Investigations in New Zealand. (1) The Profiles of some Mole-Drainage Soils and their Relation to the Depths of Mole Drains** : A. W. Hudson and C. V. Fife : *New Zealand, Department of Scientific and Industrial Research : Massey Agricultural College :* Wellington, 1941 (E. V. Paul, Government Printer), 10 in. by 6½ in. ; *N.Z.J. Sci. Tech.*, 1940, **22** (4A), 197A–208A. *Reprint.* (See also Abstract No. 9.)

22. **A Method of Design of Non-Rigid Pavements for Highways and Airport Runways** : A. T. Goldbeck : *Proc. Highw. Res. Bd., Wash.*,

1940, **20**, 258–70. Author's summary. This paper presents a method for arriving at the proper thickness of the non-rigid type of surfacing to support a given wheel load carried on a given type of tire equipment. By means of tests made in the laboratory by the use of a bin 6 ft. square, the manner of distribution of subgrade pressures has been determined under different thicknesses of from 4 to 10·in. of surfacing. Loads were applied by means of a hydraulic jack to elliptically shaped bearing blocks simulating tire imprint areas. It is assumed that a non-rigid surfacing should be of such thickness that the maximum pressure obtained under the centre of the wheel should at no time exceed the bearing value of the subgrade. A method is suggested for determining bearing value, making use of a bearing block of 100 sq. in. in area. Formulas are derived for thickness, on the arbitrary assumption that the subgrade pressures are confined within an area on the subgrade included within the lines sloping 45 deg. from the tire imprint area. The uniform pressure is then expressed in terms of the actual measured pressure, which in turn is assumed to be equal to the subgrade supporting value. Thus, formulas are derived for thickness in terms of wheel load, subgrade supporting value and the dimensions of the imprint area of the tire. These dimensions are known for given loads, tire equipment and inflation pressures. As the result of the formulas thus derived, thickness may be determined after a pressure test to ascertain the supporting power of the subgrade. For general purposes of design, the pressure tests indicate that the maximum measured pressure under stable, non-rigid surfaces may be taken at from 2 to 2½ times the uniform pressure calculated as above indicated. On this basis, curves for the required thickness are shown in terms of wheel-load and subgrade support. (See also *Road Abstr.*, 1941, 8, No. 141.)

23. **Required Thickness of Asphalt Pavement in Relation to Subgrade Support** : P. Hubbard and F. C. Field : *Asphalt Institute : Research Series* No. 8. New York, 1941 (Asphalt Institute), 9 in. by 6 in., pp. 7, fig. 3, unpriced ; *Road Abstr.*, 1942, 9, No. 34. From the results of an investigation into the failure under concentrated loads of bituminous surfacings resting on soil subgrades (see *Road Abstr.*, 1942, 9, No. 33), a working diagram has been developed to aid road and aerodrome engineers in estimating the thickness of bituminous surfacing required, on soils with different bearing capacities, for any given wheel load, with particular reference to those between 60 and 90 lb./sq. in.

24. **Building the Corpus Christi Naval Air Base** : Anon : *Engng. News-Rec.*, 1941, **127** (3), 90–5. The main site at Flour Buff of the Corpus Christi naval air training station has a landing field with four bituminous surfaced runways, each a mile long and 300 ft. wide, designed for a future width of 1,000 ft. if required. The base course of the runways was a cold mix 3½ in. thick, laid by a travelling plant in 10-ft. strips. The mix

consisted of 7½ per cent. bitumen emulsion, 46 per cent. washed shell from a nearby reef, 46 per cent. Flour Buff sand (of flour-like fineness), and ½ per cent. lime. The top course was a hot mix 1½ in. thick, consisting of 8 per cent. bitumen, 64·4 per cent. Flour Buff sand, 23 per cent. shell and 4·6 per cent. stone dust. At the outlying fields all except one of the runways has a 5-in. single-course cold-mix surfacing, made up of 55 per cent. shell, 15 per cent. concrete sand, 21½ per cent. Flour Buff sand, ½ per cent. lime and 8 per cent. emulsion, with a seal coat of hot bitumen and sand. One runway was constructed of cement-stabilized concrete sand, 6 in. thick. On all the runways the clay subgrade was stabilized with an equal volume of sand. Runways at a field intended for primary training were laid out in two 1,500-ft. diameter paved circles, 750 ft. apart, connected by a paved strip 400 ft. wide, so that aircraft could land and take off in any direction.

25. **A New Method of Constructing Brick Surfacings** : W. Freytag : *Strassenbau*, 1941, **32** (7), 93–5 ; (8), 103–5 ; *Road Abstr.*, 1942, **9**, No. 45. Low-cost brick surfacings constructed experimentally on aerodrome runways, hangar aprons, etc., have proved stable under the stresses imposed by both heavy traffic and starting and alighting aircraft. The surfacings are laid on a sand bedding course directly on the well-compacted subsoil with no intervening foundation course, and their resistance to traffic stresses is attributed to the method of setting the bricks very close together in a series of short arches separated by single courses of brick. The standard road bricks, 10 by 4·8 by 2·6 in. (25 by 12 by 6·5 cm.), generally used are laid in bays about 16·5 ft. (5 m.) wide, constructed at right angles to the length of the runway and separated by single courses of brick placed on edge ; the paved area is enclosed by stone or concrete kerbs. Each bay has a roof-shaped cross-section with a camber not exceeding 1 in 50. When the formation has been thoroughly compacted the separating courses are laid, a sand bedding course is placed to a depth of 1·6 to 2·4 in. (4 to 6 cm.), and the bricks are laid by hand as close as possible in staggered transverse courses. The bricks are laid 0·6 to 0·8 in. (1·5 to 2 cm.) above the eventual surface level. Before compaction, fine sand is swept or washed into the joints, and all sand, dirt, and small stones are removed from the surface. The surfacing is rolled by a three-wheeled or tandem roller weighing about 3 tons. Although the slip-stream from aircraft propellers generally removes the sand from the joints to a depth of nearly ½ in. (1 cm.), no damage has resulted. Since this type of surfacing is not waterproof its use should, in general, be confined to sandy soils, but it may also be used on thoroughly compacted fillings. On large areas, such as aprons, etc., where the gradient is insufficient for adequate surface drainage, concrete channels are used. (Abstractor's Note : A similar article by the same author is published in *Flughafen*, 1941, 9 (1/2), 1–9.)

26. **Drought Aids Grading of Mobile Airport** : Anon. : *Rds and Str.*, 1941, **84** (8), 40–3. The site of Mobile airport is a hard red clay con-

taining some sand, and gravelly pieces of iron pyrites. Grading, involving the shifting of 490,000 cu. yd., was done by means of an elevating grader, tractors pulling scrapers, and bulldozers. *Drainage.* The flatness of the site made it difficult to obtain 0·4 per cent. slope of the ground for drainage, and in some of the runways the lengthwise slope is only 0·2 per cent. Concrete culverts, 6 ft. by 3 ft., and concrete pipes of different sizes were installed to handle surface storm water, one of the culverts having 4-in. square openings flush with the ground for 30 ft. of length, to act as a storm-water catch basin. No sub-drainage was provided for the runways or parking apron. *Runways.* The runways are 150 ft. wide and up to 4,300 ft. long, with provision for extension. The base is 8 in. of compacted sand-clay placed on a well-compacted subgrade. This will be followed by a priming coat of tar, and this, when cured, by a 2½-in. binder course of asphaltic concrete. The wearing course will be 1½ in. of dense graded plant-mix using 6 to 9 per cent. of 85 to 100 penetration bitumen, sealed with a coat of rapid-curing cut-back bitumen applied at the rate of 1/5 gal./sq. yd. This will immediately be covered with coarse sand or fine chippings at the rate of 10 lb./sq. yd. The mixes for both binder and wearing courses will be prepared in standard hot-mix plants and laid at 325° F.

27. **Spreader-Roller Applies Chips on Canadian Airport** : Anon. : *Constr. Meth.*, 1941, **23** (1), 45, 94 ; *Quart. Dig. curr. Asph. Lit.*, 1941, (Apr.), 16. A combination chip spreader and roller has enabled rapid progress to be made in applying stone for surface treatments on runways at Calgary, Alberta. Equipped with three 30-in. rollers, the spreader-roller spread and compacted a 10-ft. lane in one pass. Material dumped in the hopper of the machine was fed mechanically to a double-deck vibrating screen which deposited the coarser fragments first with the finer ones on top. The unit covered 5,280 sq. yd. in 50 operating minutes with 113,800 lb. of chippings. An additional 70 minutes were consumed in turning at the ends of the runways and waiting for material. The surface treatment was ¼ gal./sq. yd. of rapid-curing cut-back bitumen RC–4, covered by the spreader-roller with 20 lb. of chippings ½-in. and smaller, followed by 1/5 gal. of RC–4, covered with 20 lb. of chippings ¼-in. and smaller.

28. **Airport Runways Surfaced with Slag Asphalt on Drained Clay Subgrade** : Anon. : *Constr. Meth.*, 1940, **22** (9), 50–2, 109–10, 114, 116 ; *Road Abstr.*, 1942, 9, No. 31. The Youngstown (Ohio) airport has four 150-ft. runways, three of them 3,600 ft. and one 3,850 ft. long. Grading the site involved shifting 1,000,000 cu. yd. of earth. The runways are designed with porous edge drains and transverse tile drains on 60-ft. centres, back-filled with slag. The drainage system comprises 22 miles of pipe 6 in. to 24 in. in diameter. A compacted slag base 8 in. thick is laid on an insulation course of slag fines, providing a foundation for cold-pre-mixed, cold-laid asphaltic concrete, 2 in. thick, made with slag aggre-

gate. The maximum surface variation permitted was $\frac{1}{8}$ in. in 10 ft. Both the slag base and the bituminous surfacing were placed in two courses. Full descriptions are given of grading and drainage works and of the construction of base course and surfacing. (Abstractor's Note :—The construction of this airport is also described in *Publ. Wks, N.Y.*, 1940, **71** (11), 14–5.)

29. **Constructing Runways and Highways from Shifting Sands** : G. E. Martin : *Publ. Wks, N.Y.*, 1940, **71** (12), 22–3 ; *Road Abstr.*, 1942, 9, No. 25.

30. **Airport Winter Maintenance**: A. E. Thomas : *Rds and Str.*, 1941, **84** (11), 62, 65. Various methods have been tried of dealing with snow on the aerodrome runways 100 ft. and 150 ft. wide at the Des Moines (Iowa) airport where the paved areas are equivalent to about 30 miles of highway surfacing. One method, when the snowfall exceeds 4 or 5 in., or scattered drifts have accumulated, is to level the snow and roll it with a roller made of three 10-ft. sections of 42-in. No. 9 gauge, corrugated iron pipe. A light crawler tractor is used to pull the roller and 25-ft. widths can be rolled at a time. This method was not satisfactory, as the surface may thaw unevenly. The method of disking the crusted snow and keeping it loosened was also unsatisfactory, as drifts accumulated on the roughened areas. The minimum safe width to be cleared was not less than 100 ft., so that blade ploughs alone were of little use. The fastest, safest, and most economical method was found to be the combined use of blade ploughs with a rotary plough. The blade plough mounted on a lorry, starts down the centre of one of the runways and builds up windrows parallel to the runway. Then the rotary plough blows the snow to the nearest edge and the snow is distributed over such a large area that no banks or hazards are created. When several inches of snow covered a layer of ice from a previous storm it was found that on leaving about 1 in. to $1\frac{1}{2}$ in. of snow on top of the ice the aircraft could land safely by applying their brakes gradually.

The following are references to the more important articles on aerodromes that have been summarized in " Road Abstracts " during 1940 and 1941.

31. **Annual Winter Roads Maintenance Number (Section on Snow Removal at Airports)** : *Canad. Engr.*, 1939, **77** (16) ; *Road Abstr.*, 1940, 7, No. 136.

32. **Omaha Airport Runways : their Design, Construction and Performance** : W. H. Campen : *Rds and Str.*, 1940, **83** (5), 62, 64, 66, 68–9 ; *Road Abstr.*, 1941, 8, No. 18. Stabilized base courses over filling ; asphalt surfacings.

33. **Design and Construction of Airports** : W. Rapp : *Flughafen*, 1939, 7 (1), 18–30 ; *Road Abstr.*, 1941, 8, No. 48. Comprehensive article by official of German Air Ministry.

34. **The Drainage of Aerodromes** : D. W. Frasch : *Flughafen*, 1939, 7 (1), 30–3 ; *Road Abstr.*, 1941, 8, No. 49. By official of German Air Ministry.

35. **Vancouver's Sea Island Airport** : W. Hill : *Rds and Bridges*, 1940, 78 (4), 19–21 and 89 ; *Road Abstr.*, 1941, 8, No. 55. Semi-penetration bituminous runway surfacings.

36. **Planning North Beach Airport** : B. Somervell : *Engng News-Rec.*, 1940, **124** (13), 454–64 ; *Road Abstr.*, 1941, 8, No. 86. Asphalt macadam runways on made ground.

37. **Stresses in Concrete Runways of Airports** : H. M. Westergaard : *Proc. Highw. Res. Bd, Wash.*, 1939, 19, 197–202 ; Discussion, 202–5 ; *Road Abstr.*, 1941, 8, No. 147.

38. **Heavy Equipment Stabilizes 9-in. " Soil Concrete " Base for Washington Airport Runways**: Anon. : *Constr. Meth.*, 1940, 22 (7), 42–4, 104–6, 108–9. **Washington Airport Runways use Local Aggregates for Asphalt Pavement** : Anon. : *Constr. Meth.*, 1940, 22 (8), 42–4, 80, 82–4, 86, 88, 90 ; *Road Abstr.*, 1941, 8, No. 221.

39. **Airport Drainage and Sub-Drainage** : Anon. : *Publ. Wks, N.Y.*, 1940, 71 (11), 13, 44–5 ; *Road Abstr.*, 1941, 8, No. 286. Summary of a " Manual of Airport Drainage."